# ADULT AND JUVENILE FISH POPULATIONS OF INSHORE SOUTHEASTERN LAKE MICHIGAN NEAR THE COOK NUCLEAR POWER PLANT DURING 1973-82

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES



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LIST OF TABLES
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LIST OF TABLES
(continued)



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LIST OF TABLES
(concluded)

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## INTRODUCTION

From 1973 to 1982, adult and juvenile fish were collected from southeastern Lake Michigan near the D. C. Cook Nuclear Power Plant. The primary purpose of these field collections was to determine if the power plant affected either the abundance or distribution of fish at the plant site. Besides establishing numerical characteristics of the fish populations, general biological condition of the fish was also examined. Data on fish collected during years prior to plant operations, 1973 and 1974, were examined and reported by Jude et al. (1975, 1979). Details on evaluation of methodology are also presented in these two reports. Data on fish collected during plant operation from 1975 to 1979 are presented by Tesar et al. (1985). Also, major emphasis was directed at establishing whether statistically significant differences in catches resulted from operation of the power plant.

In this report, we present statistical evaluation of all 10 yr of data. Major emphasis again is directed toward establishing whether the power plant affected the abundance or distribution of fish at the plant site. The 10 yr of catch data show some recent shifts in the fish populations of Lake Michigan, and these are also discussed.

## METHODS

Methodology employed from 1980 to 1982 was the same as that used from 1973 to 1979. Details on sampling and statistical methodology are presented by Jude et al. (1979), and only a brief description is given here. Seven sampling stations (A,B,C,D,F,G, and H) were established in southeastern Lake Michigan at the Cook Plant and at Warren Dunes State Park (Fig. 1). These

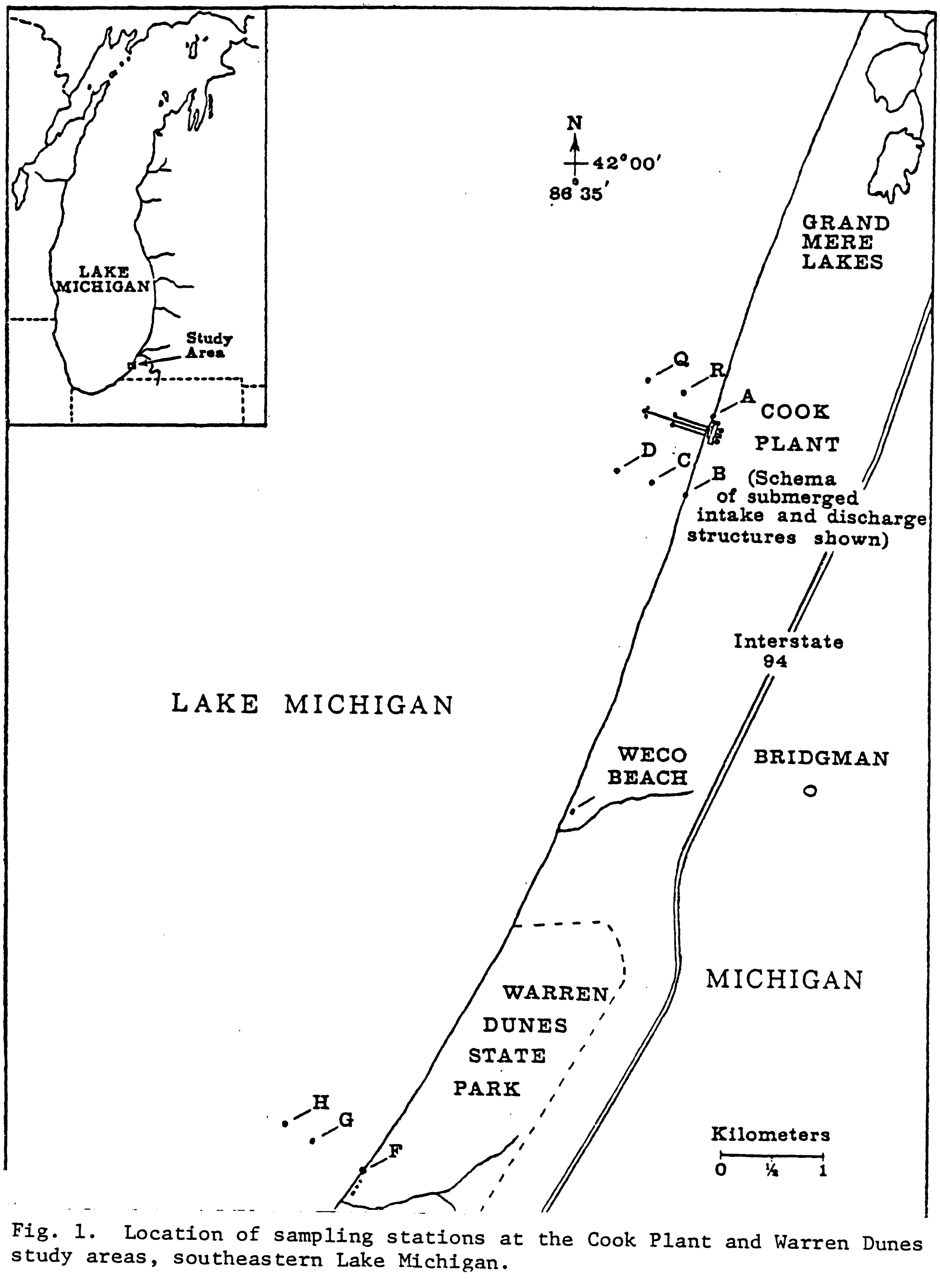


Fig. 1. Location of sampling stations at the Cook Plant and Warren Dunes study areas, southeastern Lake Michigan.

stations and data on fish collected at the stations are referred to as the standard series. Fish at 1-m beach stations A, B, and F were sampled with a 38-m x 1.8-m bag seine of 0.64-cm square mesh, while fish at 6-m stations C and G and at 9-m stations D and H were sampled with a 4.9-m bottom trawl of 3.8-cm square mesh and 160-m x 1.8-m bottom gill nets consisting of 12 mesh sizes from 1.3-cm to 10-cm square mesh. Two stations (R and Q, respectively, at 6 and 9 m) were also sampled from 1975 to 1981, north of the plant's underwater discharge and intake structures, and fish were collected by trawl at station R and by gill net at both stations. At all stations, fish were sampled during the day and at night once per month from April to November.

Physical and limnological parameters measured during sampling in 1980-1982 are presented in Appendices 1-3. Similar data for other years were presented in previous reports.

References to fish species are by common name (Table 1). Common and scientific names are according to Robins et al. (1980).

Catch data were tested parametrically by analysis of variance (ANOVA) or nonparametrically, when ANOVA assumptions were violated, by Kruskal-Wallis test. An alpha level of $<0.01$ was used for ANOVA comparisons and $<0.05$ for Kruskal-Wallis comparisons.

Tabular and graphical results in the text summarize the catch data pertaining to statistical analyses and age-group comparisons. However, complete catch data are in the appendices. Monthly catch data for all 10 yr are in Appendix 4. Appendices 5-7 summarize monthly catch data by station and gear type for 1980-1982. Similar summaries for 1973-1979 data were presented by Tesar et al. (1985). Length-frequency distributions for all species collected from 1973 to 1982 are in Appendix 8.

Table 1. Common and scientific names of fish species collected from Cook Plant study areas, southeastern Lake Michigan, 1973-1982.

| Common name | Scientific name |
|---|---|
| Alewife | *Alosa pseudoharengus* |
| Banded killifish | *Fundulus diaphanus* |
| Black bullhead | *Ictalurus melas* |
| Blackchin shiner | *Notropis heterodon* |
| Black crappie | *Pomoxis nigromaculatus* |
| Blacknose dace | *Rhinichthys atratulus* |
| Blacknose shiner | *Notropis heterolepis* |
| Bloater | *Coregonus hoyi* |
| Bluegill | *Lepomis macrochirus* |
| Bluntnose minnow | *Pimephales notatus* |
| Brook silverside | *Labidesthes sicculus* |
| Brown trout | *Salmo trutta* |
| Burbot | *Lota lota* |
| Central mudminnow | *Umbra limi* |
| Channel catfish | *Ictalurus punctatus* |
| Chinook salmon | *Oncorhynchus tshawytscha* |
| Coho salmon | *Oncorhynchus kisutch* |
| Common carp | *Cyprinus carpio* |
| Common shiner | *Notropis cornutus* |
| Creek chub | *Semotilus atromaculatus* |
| Emerald shiner | *Notropis atherinoides* |
| Fathead minnow | *Pimephales promelas* |
| Freshwater drum | *Aplodinotus grunniens* |
| Gizzard shad | *Dorosoma cepedianum* |
| Golden redhorse | *Moxostoma erythrurum* |
| Golden shiner | *Notemigonus crysoleucas* |
| Grass pickerel | *Esox americanus vermiculatus* |
| Green sunfish | *Lepomis cyanellus* |
| Johnny darter | *Etheostoma nigrum* |

(continued)

Table 1. Concluded.

| Common name | Scientific name |
|---|---|
| Lake chub | *Couesius plumbeus* |
| Lake herring | *Coregonus artedii* |
| Lake sturgeon | *Acipenser fulvescens* |
| Lake trout | *Salvelinus namaycush* |
| Lake whitefish | *Coregonus clupeaformis* |
| Largemouth bass | *Micropterus salmoides* |
| Logperch | *Percina caprodes* |
| Longnose dace | *Rhinichthys cataractae* |
| Longnose sucker | *Catostomus catostomus* |
| Mottled sculpin | *Cottus bairdi* |
| Ninespine stickleback | *Pungitius pungitius* |
| Northern pike | *Esox lucius* |
| Pumpkinseed | *Lepomis gibbosus* |
| Quillback | *Carpiodes cyprinus* |
| Rainbow smelt | *Osmerus mordax* |
| Rainbow trout | *Salmo gairdneri* |
| Rock bass | *Ambloplites rupestris* |
| Round whitefish | *Prosopium cylindraceum* |
| Sand shiner | *Notropis stramineus* |
| Shorthead redhorse | *Moxostoma macrolepidotum* |
| Silver redhorse | *Moxostoma anisurum* |
| Slimy sculpin | *Cottus cognatus* |
| Smallmouth bass | *Micropterus dolomieui* |
| Spotfin shiner | *Notropis spilopterus* |
| Spottail shiner | *Notropis hudsonius* |
| Trout-perch | *Percopsis omiscomaycus* |
| Walleye | *Stizostedion vitreum vitreum* |
| White crappie | *Pomoxis annularis* |
| White sucker | *Catostomus commersoni* |
| Yellow perch | *Perca flavescens* |

# RESULTS AND DISCUSSION

From 1973 to 1982, just over 1,100,000 fish were caught by standard series netting. The largest catch of almost 200,000 fish occurred in 1973, and the smallest catch of just under 50,000 fish occurred in 1982 (Appendix 4). Seines produced 68% of all fish collected, while trawls contributed 24% and gill nets 8%.

The total catch in 1981 was near the 10-yr average while 1980 and 1982 catches were below average. The notably small catch in 1982 resulted primarily from a drastic decline in alewife abundance; spottail shiner and trout-perch catches were also very small. In contrast, catches of yellow perch and bloater have been very large from 1980 to 1982. These fluctuations are reflective of lake-wide population changes and will be discussed for individual species.

## ABUNDANT SPECIES

### Alewife

In Lake Michigan, adult alewives reside in deep water during winter, migrate inshore in spring, spawn in shallow water and rivers in summer, and migrate offshore after spawning (Wells 1968). Young-of-the-year inhabit shallow water during summer; during fall they move offshore until the third summer of life. This schooling species also moves nocturnally shoreward and upward. As a result of being the most abundant species in Lake Michigan over the last 20 yr, alewife has substantially decreased populations of zooplankton, upon which it feeds, and fish with which it either competes or upon which it preys (Crowder 1980). Additionally, alewife is the primary forage of economically important salmonids (Stewart et al. 1981).

Alewife was the most abundant species in the study areas from 1973 to 1979. A recent population decline caused alewife to be the second- or third-most abundant species during 1980-1982.

Analyses of previous alewife catch data have shown that significant changes in abundance and distribution were the result of biological and environmental factors rather than impact of plant operation (Jude et al. 1979, Tesar et al. 1985). Examination of ANOVAs applied to 1973-1982 data produces the same conclusions (Tables 2-6). Yearly mean catches have varied 8 fold in trawls and gill nets and 5 fold in seines (Table 7). Catches from all three gear confirm a steady decline in alewife abundance since 1976. Operation of the Cook Plant was not considered a cause for alewife catch variation because (1) the catch decline in operational years also occurred in the reference area, (2) differences in catches between study areas or among seining stations were not significant, and (3) catches in operational years demonstrated no pattern in either consistently smaller or larger catches at one area or seining station (Fig. 2).

Catch data from 1980-1982 suggest that the alewife population in Lake Michigan may be headed toward collapse. While adults (age 2+) have been at low abundance since 1976, only in the past 3 yr have there been very poor year classes recruited in the study areas (Fig. 3). If lake-wide recruitment is at this low level, the population may not be able to sustain itself, particularly in face of the increasing predatory pressure from stocked salmonids.

The recent alewife decline is undoubtedly the result of predation by Lake Michigan salmonids. Since 1965, salmonid stocking rates have continually risen, thus increasing the consumption of alewife, the major salmonid prey (Stewart et al. 1981). Stewart et al. (1981) suggested that alewife

Table 2. Analysis of variance summary for log(catch + 1) of alewives. Fish were trawled from April to October, 1973-1982 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df# | Adjusted mean square† | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 9 | 9.7632 | 65.8902 | <0.0001** |
| Month | 6 | 7.1697 | 48.3876 | <0.0001** |
| Area | 1 | 0.3824 | 2.5807 | 0.1087 |
| Depth | 1 | 6.0241 | 40.6559 | <0.0001** |
| Time | 1 | 13.4390 | 90.6977 | <0.0001** |
| Y x M | 54 | 4.1559 | 28.0473 | <0.0001** |
| Y x A | 9 | 0.9087 | 6.1324 | <0.0001** |
| M x A | 6 | 0.1312 | 0.8855 | 0.5051 |
| Y x D | 9 | 0.4500 | 3.0368 | 0.0015* |
| M x D | 6 | 0.8220 | 5.5478 | <0.0001** |
| A x D | 1 | 0.4463 | 3.0117 | 0.0832 |
| Y x T | 9 | 0.7346 | 4.9580 | <0.0001** |
| M x T | 6 | 6.3057 | 42.5566 | <0.0001** |
| A x T | 1 | 0.3485 | 2.3520 | 0.1257 |
| D x T | 1 | 2.4577 | 16.5867 | 0.0001** |
| Y x M x A | 54 | 0.5029 | 3.3943 | <0.0001** |
| Y x M x D | 54 | 0.3166 | 2.1370 | <0.0001** |
| Y x A x D | 9 | 0.0759 | 0.5126 | 0.8659 |
| M x A x D | 6 | 0.6961 | 4.6978 | 0.0001** |
| Y x M x T | 54 | 2.5228 | 17.0258 | <0.0001** |
| Y x A x T | 9 | 0.8163 | 5.5088 | <0.0001** |
| M x A x T | 6 | 0.4098 | 2.7657 | 0.0117 |
| Y x D x T | 9 | 0.3029 | 2.0442 | 0.0328 |
| M x D x T | 6 | 0.3831 | 2.5852 | 0.0177 |
| A x D x T | 1 | 0.0232 | 0.1564 | 0.6927 |
| Y x M x A x D | 54 | 0.3027 | 2.0428 | <0.0001** |
| Y x M x A x T | 54 | 0.3630 | 2.4499 | <0.0001** |
| Y x M x D x T | 54 | 0.3340 | 2.2539 | <0.0001** |
| Y x A x D x T | 9 | 0.1947 | 1.3140 | 0.2262 |
| M x A x D x T | 6 | 0.3955 | 2.6691 | 0.0146 |
| Y x M x A x D x T | 54 | 0.1879 | 1.2681 | 0.1019 |
| Within cell error | 558 | 0.1482 | | |

# Two degrees of freedom were subtracted from the error term to correct for two missing observations where the cell means were substituted.

† Mean squares were multiplied by harmonic mean cell size/maximum cell size (nh/n = 0.9964) to correct for two missing observations where the cell means were substituted.

** Highly significant ($P < 0.001$).

* Significant ($P < 0.01$).

Table 3. Analysis of variance summary for log(catch + 1) of alewives. Fish were trawled from April to October, 1975-1981 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df | Mean square | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 6 | 7.0482 | 45.8230 | <0.0001** |
| Month | 6 | 15.5149 | 100.8677 | <0.0001** |
| Station | 4 | 1.8131 | 11.7873 | <0.0001** |
| Time | 1 | 5.8505 | 38.0363 | <0.0001** |
| Y x M | 36 | 4.4540 | 28.9574 | <0.0001** |
| Y x S | 24 | 0.4259 | 2.7688 | <0.0001** |
| M x S | 24 | 0.5477 | 3.5609 | <0.0001** |
| Y x T | 6 | 1.3957 | 9.0741 | <0.0001** |
| M x T | 6 | 7.8534 | 51.0580 | <0.0001** |
| S x T | 4 | 1.4399 | 9.3615 | <0.0001** |
| Y x M x S | 144 | 0.3080 | 2.0024 | <0.0001** |
| Y x M x T | 36 | 2.6273 | 17.0807 | <0.0001** |
| Y x S x T | 24 | 0.2685 | 1.7455 | 0.0163 |
| M x S x T | 24 | 0.1943 | 1.2634 | 0.1822 |
| Y x M x S x T | 144 | 0.2762 | 1.7955 | <0.0001** |
| Within cell error | 490 | 0.1538 | | |

** Highly significant (P < 0.001).

Table 4. Analysis of variance summary for log(catch + 1) of alewives. Fish were gillnetted from April to September, 1973-1982 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df | Mean square | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 9 | 5.4627 | 40.6653 | <0.0001** |
| Month | 5 | 18.2590 | 135.9231 | <0.0001** |
| Area | 1 | 0.1277 | 0.9502 | 0.3349 |
| Depth | 1 | 1.0541 | 7.8469 | 0.0075* |
| Time | 1 | 23.5165 | 175.0609 | <0.0001** |
| Y x M | 45 | 1.0077 | 7.5016 | <0.0001** |
| Y x A | 9 | 0.1934 | 1.4394 | 0.2004 |
| M x A | 5 | 0.3082 | 2.2943 | 0.0611 |
| Y x D | 9 | 0.1322 | 0.9840 | 0.4662 |
| M x D | 5 | 0.9097 | 6.7722 | 0.0001** |
| A x D | 1 | 0.2237 | 1.6650 | 0.2035 |
| Y x T | 9 | 1.2383 | 9.2182 | <0.0001** |
| M x T | 5 | 1.3235 | 9.8525 | <0.0001** |
| A x T | 1 | 0.0000 | 0.0001 | 0.9911 |
| D x T | 1 | 1.7059 | 12.6992 | 0.0009** |
| Y x M x A | 45 | 0.2757 | 2.0522 | 0.0088* |
| Y x M x D | 45 | 0.3147 | 2.3424 | 0.0026* |
| Y x A x D | 9 | 0.1051 | 0.7826 | 0.6333 |
| M x A x D | 5 | 0.0586 | 0.4364 | 0.8208 |
| Y x M x T | 45 | 0.7469 | 5.5598 | <0.0001** |
| Y x A x T | 9 | 0.4160 | 3.0968 | 0.0056* |
| M x A x T | 5 | 0.1056 | 0.7861 | 0.5652 |
| Y x D x T | 9 | 0.1267 | 0.9432 | 0.4982 |
| M x D x T | 5 | 0.1374 | 1.0229 | 0.4156 |
| A x D x T | 1 | 0.1106 | 0.8234 | 0.3690 |
| Y x M x A x D | 45 | 0.1487 | 1.1068 | 0.3676 |
| Y x M x A x T | 45 | 0.1235 | 0.9193 | 0.6105 |
| Y x M x D x T | 45 | 0.2621 | 1.9510 | 0.0136 |
| Y x A x D x T | 9 | 0.0733 | 0.5460 | 0.8329 |
| M x A x D x T | 5 | 0.2125 | 1.5820 | 0.1845 |
| Y x M x A x D x T§ | 45 | 0.1343 | | |

** Highly significant (P < 0.001).
* Significant (P < 0.01).
§ The Y x M x A x D x T interaction is assumed to be zero and its mean square treated as the within cell error mean square.

Table 5. Analysis of variance summary for log(catch + 1) of alewives. Fish were gillnetted from April to September, 1975-1981 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df | Mean square | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 6 | 2.9599 | 20.3344 | <0.0001** |
| Month | 5 | 16.2356 | 111.5386 | <0.0001** |
| Area | 2 | 0.3172 | 2.1793 | 0.1220 |
| Depth | 1 | 3.2745 | 22.4956 | <0.0001** |
| Time | 1 | 23.3442 | 160.3743 | <0.0001** |
| Y x M | 30 | 1.7686 | 12.1501 | <0.0001** |
| Y x A | 12 | 0.1721 | 1.1823 | 0.3164 |
| M x A | 10 | 0.1673 | 1.1494 | 0.3424 |
| Y x D | 6 | 0.1602 | 1.1006 | 0.3727 |
| M x D | 5 | 1.2772 | 8.7742 | <0.0001** |
| A x D | 2 | 0.1388 | 0.9539 | 0.3910 |
| Y x T | 6 | 1.1725 | 8.0550 | <0.0001** |
| M x T | 5 | 1.7395 | 11.9502 | <0.0001** |
| A x T | 2 | 0.3237 | 2.2235 | 0.1171 |
| D x T | 1 | 0.2852 | 1.9591 | 0.1668 |
| Y x M x A | 60 | 0.2354 | 1.6170 | 0.0325 |
| Y x M x D | 30 | 0.2167 | 1.4884 | 0.0951 |
| Y x A x D | 12 | 0.1020 | 0.7005 | 0.7447 |
| M x A x D | 10 | 0.2061 | 1.4157 | 0.1956 |
| Y x M x T | 30 | 1.0784 | 7.4089 | <0.0001** |
| Y x A x T | 12 | 0.2529 | 1.7371 | 0.0811 |
| M x A x T | 10 | 0.1185 | 0.8144 | 0.6159 |
| Y x D x T | 6 | 0.2499 | 1.7166 | 0.1327 |
| M x D x T | 5 | 0.1422 | 0.9773 | 0.4391 |
| A x D x T | 2 | 0.4014 | 2.7580 | 0.0715 |
| Y x M x A x D | 60 | 0.1710 | 1.1749 | 0.2671 |
| Y x M x A x T | 60 | 0.2202 | 1.5126 | 0.0559 |
| Y x M x D x T | 30 | 0.3659 | 2.5138 | 0.0012* |
| Y x A x D x T | 12 | 0.0389 | 0.2671 | 0.9922 |
| M x A x D x T | 10 | 0.1254 | 0.8613 | 0.5733 |
| Y x M x A x D x T§ | 60 | 0.1456 | | |

** Highly significant (P < 0.001).
* Significant (P < 0.01).
§ The Y x M x A x D x T interaction is assumed to be zero and its mean square treated as the within cell error mean square.

Table 6. Analysis of variance summary for log(catch + 1) of alewives. Fish were seined from April to October, 1973-1982 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df# | Adjusted mean square† | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 9 | 7.1859 | 50.5011 | <0.0001** |
| Month | 6 | 37.8533 | 266.0271 | <0.0001** |
| Station | 2 | 0.4708 | 3.3088 | 0.0375 |
| Time | 1 | 8.3766 | 58.8696 | <0.0001** |
| Y x M | 54 | 5.5908 | 39.2914 | <0.0001** |
| Y x S | 18 | 0.5788 | 4.0679 | <0.0001** |
| M x S | 12 | 1.1873 | 8.3441 | <0.0001** |
| Y x T | 9 | 1.6696 | 11.7334 | <0.0001** |
| M x T | 6 | 25.5224 | 179.3678 | <0.0001** |
| S x T | 2 | 0.4011 | 2.8190 | 0.0608 |
| Y x M x S | 108 | 0.7323 | 5.1466 | <0.0001** |
| Y x M x T | 54 | 3.4409 | 24.1824 | <0.0001** |
| Y x S x T | 18 | 0.9615 | 6.7574 | <0.0001** |
| M x S x T | 12 | 0.3842 | 2.6999 | 0.0016* |
| Y x M x S x T | 108 | 0.4291 | 3.0157 | <0.0001** |
| Within cell error | 419 | 0.1423 | | |

# One degree of freedom was subtracted from the error term to correct for one missing observation where the cell mean was substituted.
† Mean squares were multiplied by harmonic mean cell size/maximum cell size (nh/n = 0.9976) to correct for one missing observation where the cell mean was substituted.
** Highly significant (P < 0.001).
* Significant (P < 0.01).

Table 7. Geometric mean number (+ 1) of alewives caught by trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan. NC = north Cook, SC = south Cook, WD = Warren Dunes, D = day, N = night, station A = 1 m north Cook, B = 1 m south Cook, F = 1 m Warren Dunes, C = 6 m south Cook, D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes, R = 6 m north Cook.

| Year | | | | | | | | | | Month | | | | | | | Area | | | Depth | | Time | | Station | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | Ap | Ma | Ju | Ju | Au | Se | Oc | NC | SC | WD | 6m | 9m | D | N | A | B | F | C | D | G | H | R |
| Trawl (1973-1982 standard series data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 25 | 19 | 6 | 15 | 7 | 3 | 5 | 6 | 11 | 4 | 5 | 16 | 12 | 7 | 4 | 6 | 12 | | 8 | 8 | 10 | 7 | 11 | 6 | | | | | | | | |
| Trawl (1975-1981 data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 8 | 17 | 7 | 3 | 6 | 7 | 10 | | 3 | 16 | 13 | 6 | 3 | 6 | 17 | | | | | | 9 | 6 | | | | 8 | 5 | 8 | 6 | 9 |
| Gill net (1973-1982 standard series data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 55 | 72 | 13 | 42 | 14 | 10 | 18 | 14 | 11 | 7 | 17 | 37 | 74 | 36 | 8 | 4 | | | 20 | 18 | 21 | 17 | 11 | 32 | | | | | | | | |
| Gill net (1975-1981 data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 12 | 41 | 16 | 11 | 20 | 16 | 11 | | 11 | 37 | 45 | 36 | 7 | 4 | | 18 | 17 | 15 | 20 | 14 | 10 | 27 | | | | | | | | |
| Seine (1973-1982 standard series data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 25 | 22 | 25 | 37 | 20 | 10 | 20 | 7 | 7 | 5 | 1 | 7 | 24 | 13 | 72 | 49 | 14 | | | | | | 19 | 12 | 16 | 14 | 14 | | | | | |

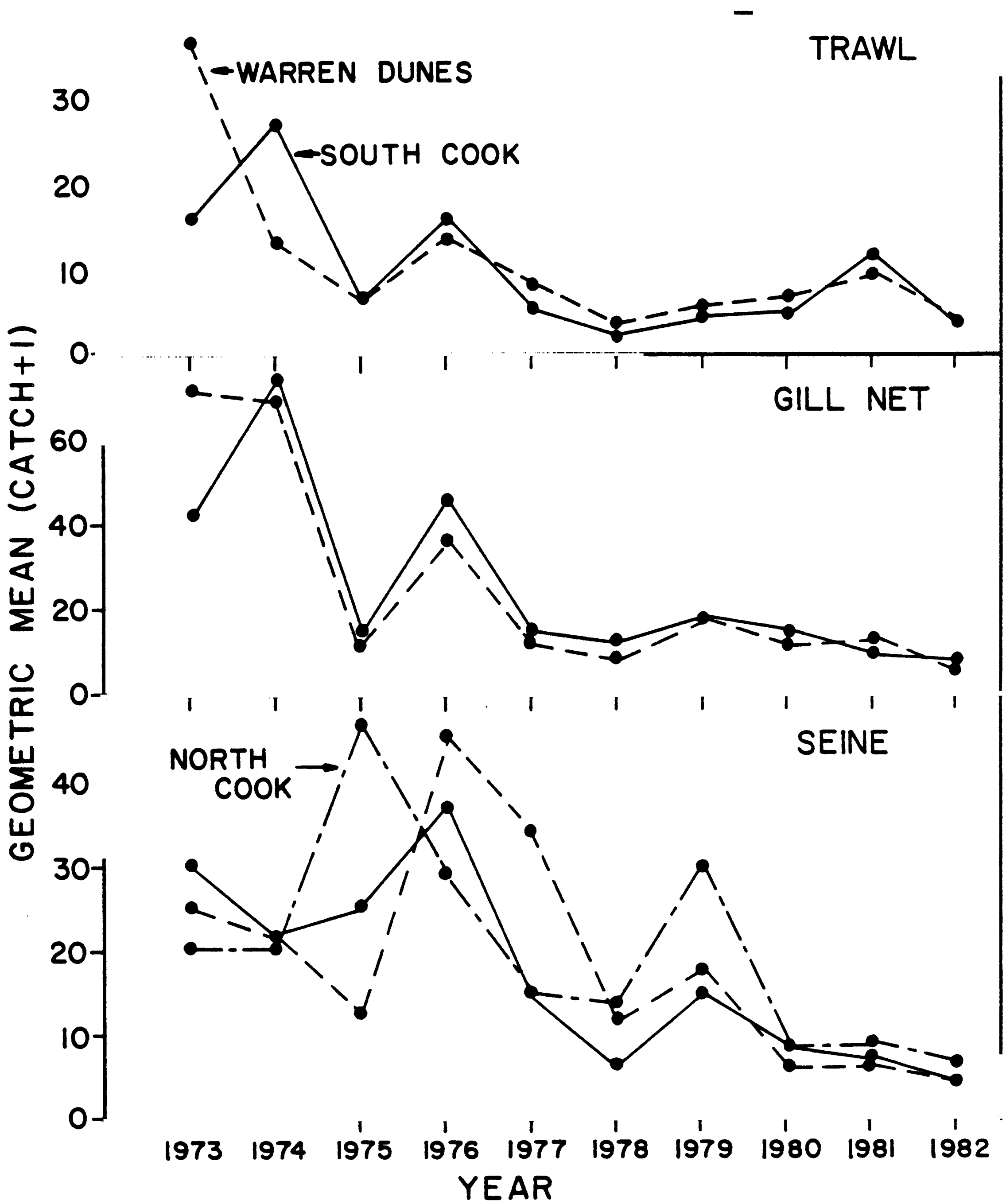


Fig. 2. Yearly geometric mean number of alewives caught by standard series trawling, gillnetting, and seining in the study areas of southeastern Lake Michigan. The Cook Plant began operation in 1975.

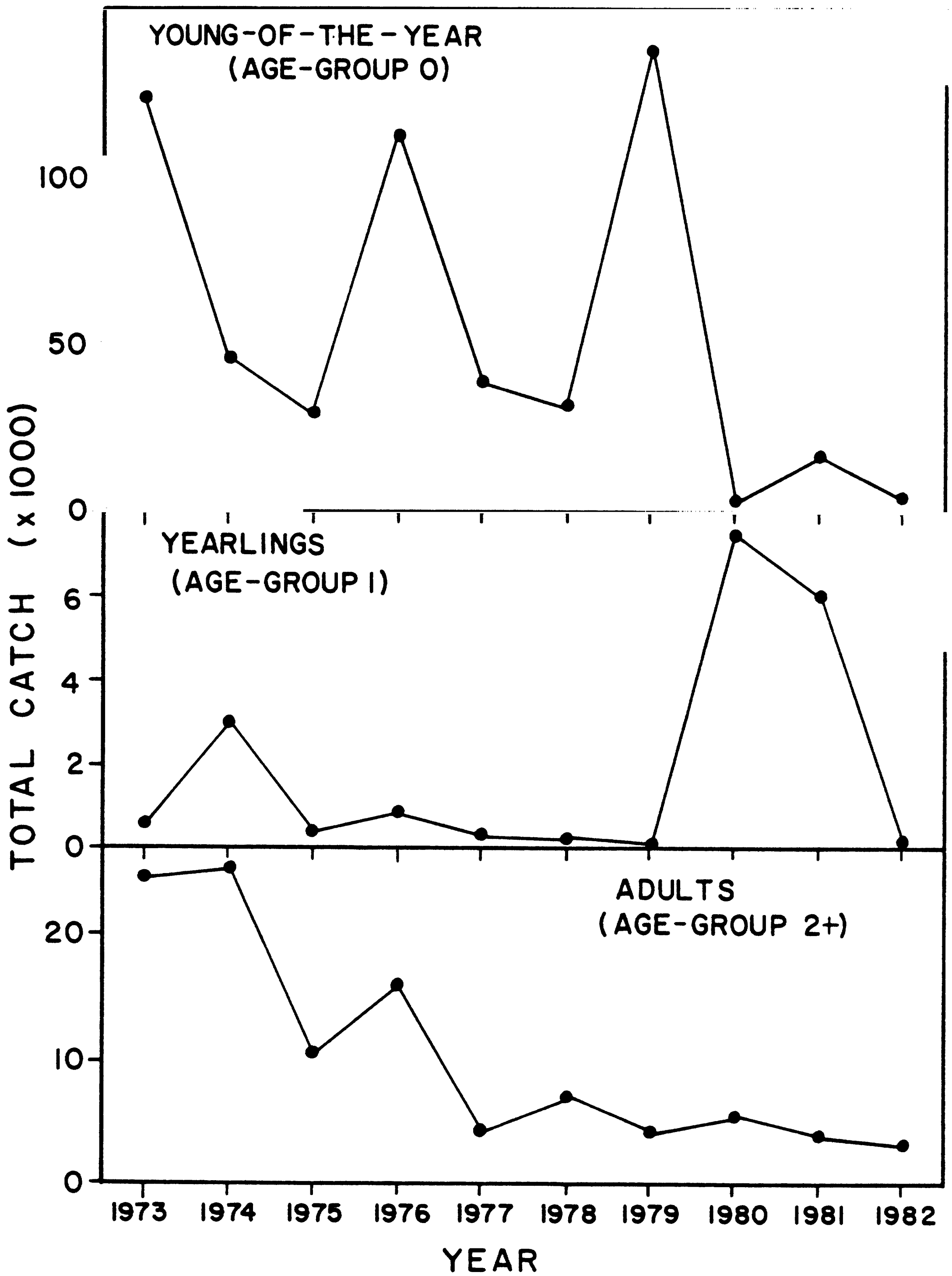


Fig. 3. Yearly total catch of three age-groups of alewives. Fish were caught from April to October by standard series netting in Cook Plant study areas, southeastern Lake Michigan.

production would decline, thus destabilizing the current predator-prey system. Whether the alewife population collapses or recovers depends on salmonid stocking rates, production of other prey species, and ability of salmonids to switch to alternate prey.

Bloater

The bloater population in Lake Michigan reached a peak in the early 1960s, after deepwater coregonid competitors had been decimated by overfishing and sea lamprey predation (Smith 1964). However, by the late 1960s, the bloater also began to decrease (Brown 1970); by the early 1970s the decline was substantial enough to cause closure of the commercial fishery in 1976. Bloaters prefer cold water, and during most months fish reside deeper than 18 m in Lake Michigan (Wells 1968). During summer, bloaters move shoreward with upwelling of the thermocline.

From 1973 to 1977, annual bloater catches in the study areas averaged almost 150 fish per year. In 1978, abundance started to increase, and from 1978 to 1982 catches averaged just over 3,700 fish per year. Yearly catches peaked in 1981 when almost 10,000 bloaters were caught. The catch in 1982 fell to approximately 1,500 fish. Ninety-three percent of all bloaters caught were trawled. Therefore, only trawl catch data were sufficient and consistent enough for statistical treatment.

Analyses of 1973 to 1979 seine and gill net catch data revealed no changes or trends in distribution or abundance of bloaters which could be attributed to plant operation (Tesar et al. 1985). Seine and gill net data from 1980 to 1982 also showed no plant-related changes or trends in bloater abundance. Analyses of 1973-1979 trawl data demonstrated no significant changes in catch attributable to the power plant (Tesar et al. 1985).

Lack of significance between area catches in operational years 1975-1982 again indicates that plant operation did not affect bloater abundance or distribution (Table 8). The significantly larger catch in only the Cook area during operational years compared to preoperational years was assumed to be a result of the 1978-1982 population increase (Table 8). Only June trawl catch data were tested because during July-September upwellings temperature differences in the two study areas substantially affected bloater catches. Trawl data for 1980-1982 show that the population increase which began in 1978 reached a peak in 1981 (Fig. 4).

Most bloaters collected in the study areas were yearlings or young-of-the-year (Fig. 5). Young-of-the-year were collected in the fall, while yearlings and adults were collected in June and other summer months during upwelling. Year-class strength of bloaters varied considerably during the last 5 yr of the study. The 1980 year class was particularly strong, especially as yearlings in 1981. The decline of all age-groups in 1982 catches may be related to water temperature, as no upwelling events were encountered during summer sampling. Thus, bloaters were distributed offshore from the study areas when sampling occurred.

The bloater population increase during the last 5 yr of this study is clearly related to commercial fishing. The fishery was closed in 1976, and the next year a strong year class was produced (Fig. 5). Continued closure of the fishery has allowed the population to increase substantially. The decline in the alewife, a competing species, may also have contributed to the bloater increase. In 1980, bloaters and yellow perch produced very strong year classes. This was also the first year that both young-of-the-year and

Table 8. Results of the Kruskal-Wallis test applied to June, 1973-1982 bloater trawl catch data from Cook Plant study areas, southeastern Lake Michigan. Sta = stations(s), C = 6 m south Cook, D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes.

| Source of variation | H Statistic | Significance |
|---|---|---|
| Sta C (1973-74) vs. Sta G (1973-74) | 0.02083 | 0.8852 |
| Sta D (1973-74) vs. Sta H (1973-74) | 0.00000 | 0.9999 |
| Sta C,D (1973-74) vs. Sta G,H (1973-74) | 0.17647 | 0.6744 |
| Sta C (1973-74) vs. Sta C (1975-82) | 3.05580 | 0.0804 |
| Sta D (1973-74) vs. Sta D (1975-82) | 2.58040 | 0.1082 |
| Sta G (1973-74) vs. Sta G (1975-82) | 2.43080 | 0.1190 |
| Sta H (1973-74) vs. Sta H (1975-82) | 0.10937 | 0.7409 |
| Sta C,D (1973-74) vs. Sta C,D (1975-82) | 5.44320 | 0.0196* |
| Sta G,H (1973-74) vs. Sta G,H (1975-82) | 1.92190 | 0.1657 |
| Sta C (1975-82) vs. Sta G (1975-82) | 0.24006 | 0.6242 |
| Sta D (1975-82) vs. Sta H (1975-82) | 0.22195 | 0.6376 |
| Sta C,D (1975-82) vs. Sta G,H (1975-82) | 0.00162 | 0.9679 |

*Significant ($P < 0.05$).

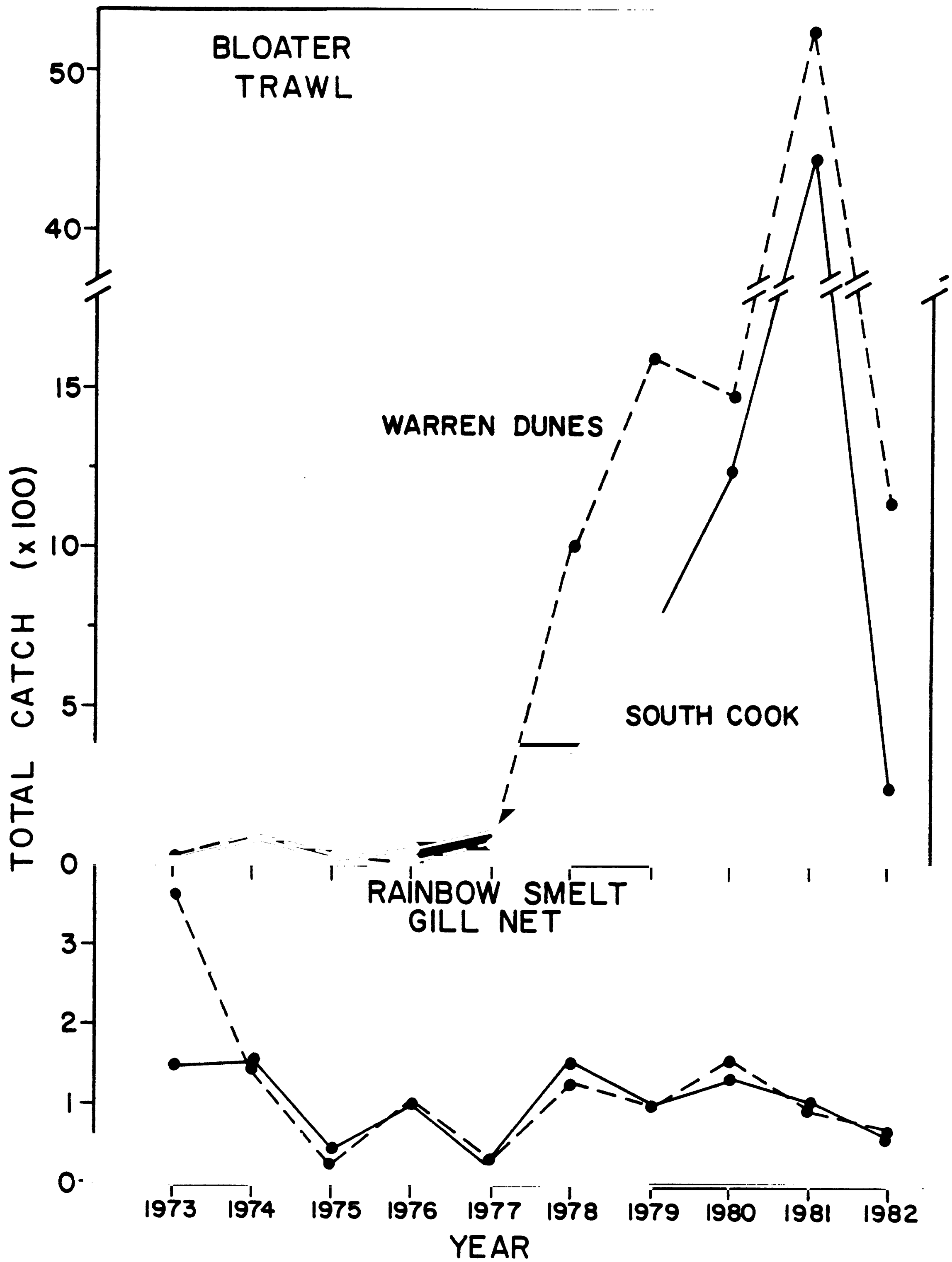


Fig. 4. Annual catches of bloater and rainbow smelt in the study areas of southeastern Lake Michigan. The Cook Plant began operation in 1975.

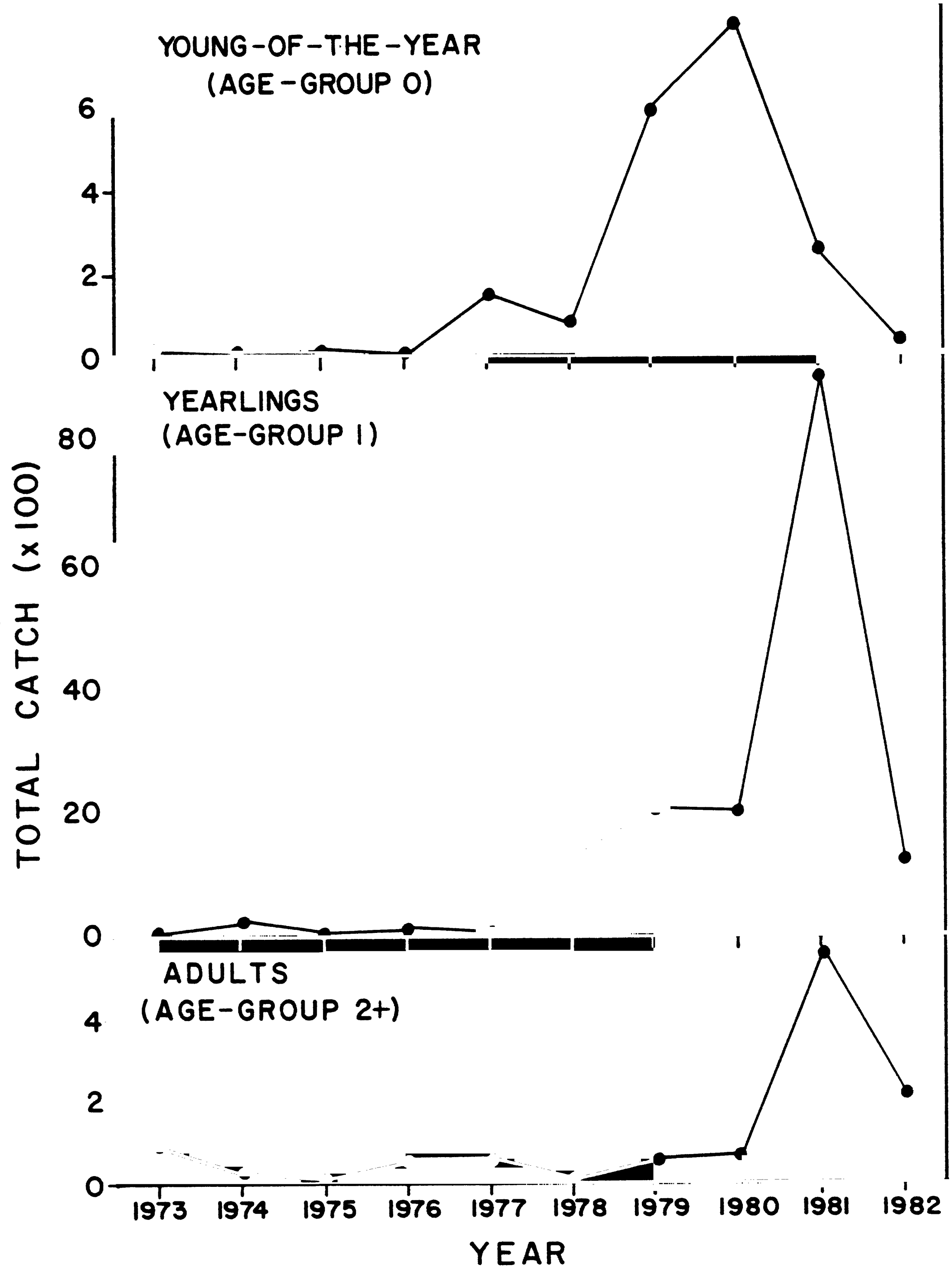


Fig. 5. Yearly total catch of three age-groups of bloaters. Fish were caught from April to October by standard series netting in Cook Plant study areas, southeastern Lake Michigan.

adult alewives were in very low abundance. These findings suggest that the alewife may have suppressed these species.

Rainbow Smelt

After being introduced into Lake Michigan in 1912, rainbow smelt became a dominant species whose population apparently peaked in the early 1940s but declined in the early 1960s (Wells and McLain 1973). Rainbow smelt is an important commercial and sport species, and it also is important forage for Lake Michigan salmonids (Stewart et al. 1981). Adults reside on the bottom in cold water at 13 to 37 m (Wells 1968). They spawn inshore in spring and also move inshore during cold-water upwelling. Juveniles are pelagic and remain closer inshore.

Total catches of rainbow smelt in 1981 and 1980 were, respectively, the second and third largest over the 10-yr sampling period (Appendix 4). Large trawl catches accounted for most of the increase. The 1982 catch was near the 10-yr average catch of approximately 7,700 fish. The rainbow smelt population has increased recently, since reaching a low in 1976 and 1977.

Analyses of catch data have shown considerable fluctuation in yearly abundance and distribution of rainbow smelt (Jude et al. 1979). These fluctuations are primarily the result of variable year-class strength and water temperature. This species prefers cold water, and its depth distribution is regulated by the seasonal rate of warming and movement of the thermocline. Analyses have shown no changes in the rainbow smelt population attributable to plant operation (Tesar et al. 1985). Examination of ANOVAs applied to all 10 yr of catch data resulted in the same conclusion (Tables 9-11). Yearly mean trawl and seine catches have, respectively, varied 9 and 12 fold (Table 12). The yearly total gill net catches have varied 8 fold. Plant operation was not

Table 9. Analysis of variance summary for log(catch + 1) of rainbow smelt. Fish were trawled from April to October, 1973-1982 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df# | Adjusted mean square† | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 9 | 11.6775 | 190.3149 | <0.0001** |
| Month | 6 | 20.9285 | 341.0830 | <0.0001** |
| Area | 1 | 1.2705 | 20.7067 | <0.0001** |
| Depth | 1 | 18.4224 | 300.2393 | <0.0001** |
| Time | 1 | 2.1608 | 35.2149 | <0.0001** |
| Y x M | 54 | 5.1984 | 84.7207 | <0.0001** |
| Y x A | 9 | 0.1838 | 2.9958 | 0.0017* |
| M x A | 6 | 0.5503 | 8.9680 | <0.0001** |
| Y x D | 9 | 0.8416 | 13.7163 | <0.0001** |
| M x D | 6 | 0.3032 | 4.9418 | 0.0001** |
| A x D | 1 | 0.0658 | 1.0718 | 0.3010 |
| Y x T | 9 | 1.2075 | 19.6785 | <0.0001** |
| M x T | 6 | 1.9583 | 31.9153 | <0.0001** |
| A x T | 1 | 0.0712 | 1.1601 | 0.2819 |
| D x T | 1 | 1.3609 | 22.1786 | <0.0001** |
| Y x M x A | 54 | 0.4068 | 6.6301 | <0.0001** |
| Y x M x D | 54 | 0.7164 | 11.6753 | <0.0001** |
| Y x A x D | 9 | 0.2843 | 4.6335 | <0.0001** |
| M x A x D | 6 | 0.3384 | 5.5148 | <0.0001** |
| Y x M x T | 54 | 1.0871 | 17.7173 | <0.0001** |
| Y x A x T | 9 | 0.1109 | 1.8079 | 0.0641 |
| M x A x T | 6 | 0.2622 | 4.2735 | 0.0003** |
| Y x D x T | 9 | 0.3021 | 4.9235 | <0.0001** |
| M x D x T | 6 | 0.7684 | 12.5233 | <0.0001** |
| A x D x T | 1 | 0.1407 | 2.2929 | 0.1305 |
| Y x M x A x D | 54 | 0.1455 | 2.3719 | <0.0001** |
| Y x M x A x T | 54 | 0.2109 | 3.4370 | <0.0001** |
| Y x M x D x T | 54 | 0.3180 | 5.1821 | <0.0001** |
| Y x A x D x T | 9 | 0.2123 | 3.4601 | 0.0004** |
| M x A x D x T | 6 | 0.0922 | 1.5029 | 0.1748 |
| Y x M x A x D x T | 54 | 0.1972 | 3.2131 | <0.0001** |
| Within cell error | 558 | 0.0614 | | |

# Two degrees of freedom were subtracted from the error term to correct for two missing observations where the cell means were substituted.
† Mean squares were multiplied by harmonic mean cell size/maximum cell size (nh/n = 0.9964) to correct for two missing observations where the cell means were substituted.
** Highly significant (P < 0.001).
* Significant (P < 0.01).

Table 10. Analysis of variance summary for log(catch + 1) of rainbow smelt. Fish were trawled from April to October, 1975-1981 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df | Mean square | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 6 | 17.8718 | 253.1224 | <0.0001** |
| Month | 6 | 16.0074 | 226.7162 | <0.0001** |
| Station | 4 | 2.3031 | 32.6189 | <0.0001** |
| Time | 1 | 2.7120 | 38.4110 | <0.0001** |
| Y x M | 36 | 7.4359 | 105.3169 | <0.0001** |
| Y x S | 24 | 0.3847 | 5.4486 | <0.0001** |
| M x S | 24 | 0.3086 | 4.3713 | <0.0001** |
| Y x T | 6 | 0.8030 | 11.3731 | <0.0001** |
| M x T | 6 | 2.6366 | 37.3433 | <0.0001** |
| S x T | 4 | 0.8109 | 11.4843 | <0.0001** |
| Y x M x S | 144 | 0.3373 | 4.7768 | <0.0001** |
| Y x M x T | 36 | 1.1615 | 16.4500 | <0.0001** |
| Y x S x T | 24 | 0.2074 | 2.9372 | <0.0001** |
| M x S x T | 24 | 0.2152 | 3.0484 | <0.0001** |
| Y x M x S x T | 144 | 0.2029 | 2.8738 | <0.0001** |
| Within cell error | 490 | 0.0706 | | |

** Highly significant (P < 0.001).

Table 11. Analysis of variance summary for log(catch + 1) of rainbow smelt. Fish were seined from April to May, 1973-1982 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df | Mean square | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 9 | 2.0141 | 28.1013 | <0.0001** |
| Month | 1 | 0.0015 | 0.0211 | 0.8846 |
| Station | 2 | 0.1303 | 1.8186 | 0.1667 |
| Time | 1 | 23.7962 | 332.0076 | <0.0001** |
| Y x M | 9 | 1.3658 | 19.0564 | <0.0001** |
| Y x S | 18 | 0.3215 | 4.4853 | <0.0001** |
| M x S | 2 | 0.0121 | 0.1683 | 0.8453 |
| Y x T | 9 | 0.7324 | 10.2183 | <0.0001** |
| M x T | 1 | 0.0426 | 0.5946 | 0.4422 |
| S x T | 2 | 0.0764 | 1.0664 | 0.3475 |
| Y x M x S | 18 | 0.2003 | 2.7951 | 0.0005** |
| Y x M x T | 9 | 1.4456 | 20.1692 | <0.0001** |
| Y x S x T | 18 | 0.5179 | 7.2262 | <0.0001** |
| M x S x T | 2 | 0.7008 | 9.7778 | 0.0001** |
| Y x M x S x T | 18 | 0.4070 | 5.6791 | <0.0001** |
| Within cell error | 120 | 0.0717 | | |

** Highly significant (P < 0.001).

Table 12. Geometric mean number (+ 1) of rainbow smelt caught by trawling and seining in Cook Plant study areas, southeastern Lake Michigan. SC = south Cook, WD = Warren Dunes, D = day, N = night, station A = 1 m north Cook, B = 1 m south Cook, F = 1 m Warren Dunes, C = 6 m south Cook, D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes, R = 6 m north Cook.

| Year | | | | | | | | | | Month | | | | | | | Area | | Depth | | Time | | Station | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | Ap | Ma | Ju | Ju | Au | Se | Oc | SC | WD | 6m | 9m | D | N | A | B | F | C | D | G | H | R |
| | | | | | | | | | | Trawl (1973-1982 standard series data) | | | | | | | | | | | | | | | | | | | | |
| 29 | 9 | 6 | 3 | 5 | 12 | 12 | 28 | 15 | 9 | 21 | 46 | 6 | 6 | 10 | 4 | 8 | 9 | 11 | 8 | 14 | 9 | 11 | | | | | | | | |
| | | | | | | | | | | Trawl (1975-1981 data) | | | | | | | | | | | | | | | | | | | | |
| | | 6 | 2 | 5 | 12 | 13 | 29 | 13 | | 15 | 39 | 6 | 8 | 5 | 4 | 6 | | | | | 8 | 10 | | | | 7 | 10 | 8 | 12 | 7 |
| | | | | | | | | | | Seine (1973-1982 standard series data) | | | | | | | | | | | | | | | | | | | | |
| 12 | 3 | 4 | 3 | 1 | 1 | 3 | 3 | 2 | 5 | 3 | 3 | | | | | | | | | | 2 | 6 | 3 | 3 | 3 | | | | | |

considered the cause of these fluctuations because (1) yearly changes occurred simultaneously in both study areas and (2) no consistent pattern emerged between preoperational and operational years' catches (Figs. 4 and 6). There was a significantly larger trawl catch at Warren Dunes; however, this occurred during preoperational and operational years.

Most rainbow smelt caught in the study areas were yearlings and young-of-the-year (Fig. 7). Abundances of these age-groups varied considerably, partly the result of variable year-class strength. Except for 1973, abundance of adults has remained stable.

During the last 3 yr of the study, catches of yearlings have been large. This may be the result of the recent decline in the alewife, a competing species. Both species are planktivorous as juveniles, and a smaller alewife population would leave more zooplankton for juvenile rainbow smelt, presumably resulting in greater survival of yearlings. However, no increase in adult rainbow smelt has occurred.

Spottail Shiner

During the 10 study yr, the yearly spottail shiner catch has averaged over 23,000 fish. The 1981 catch was near average, while the 1980 catch was the second highest of the 10 yr. In 1982, the total of almost 13,000 fish was the smallest ever. Small seine catches in 1982 accounted for most of the decline. Compared to the other abundant species, spottail shiner catches have been relatively stable. Although the population overwinters in 9-30-m-deep water (Wells 1968), this species is one of only four species resident in the shallow study areas.

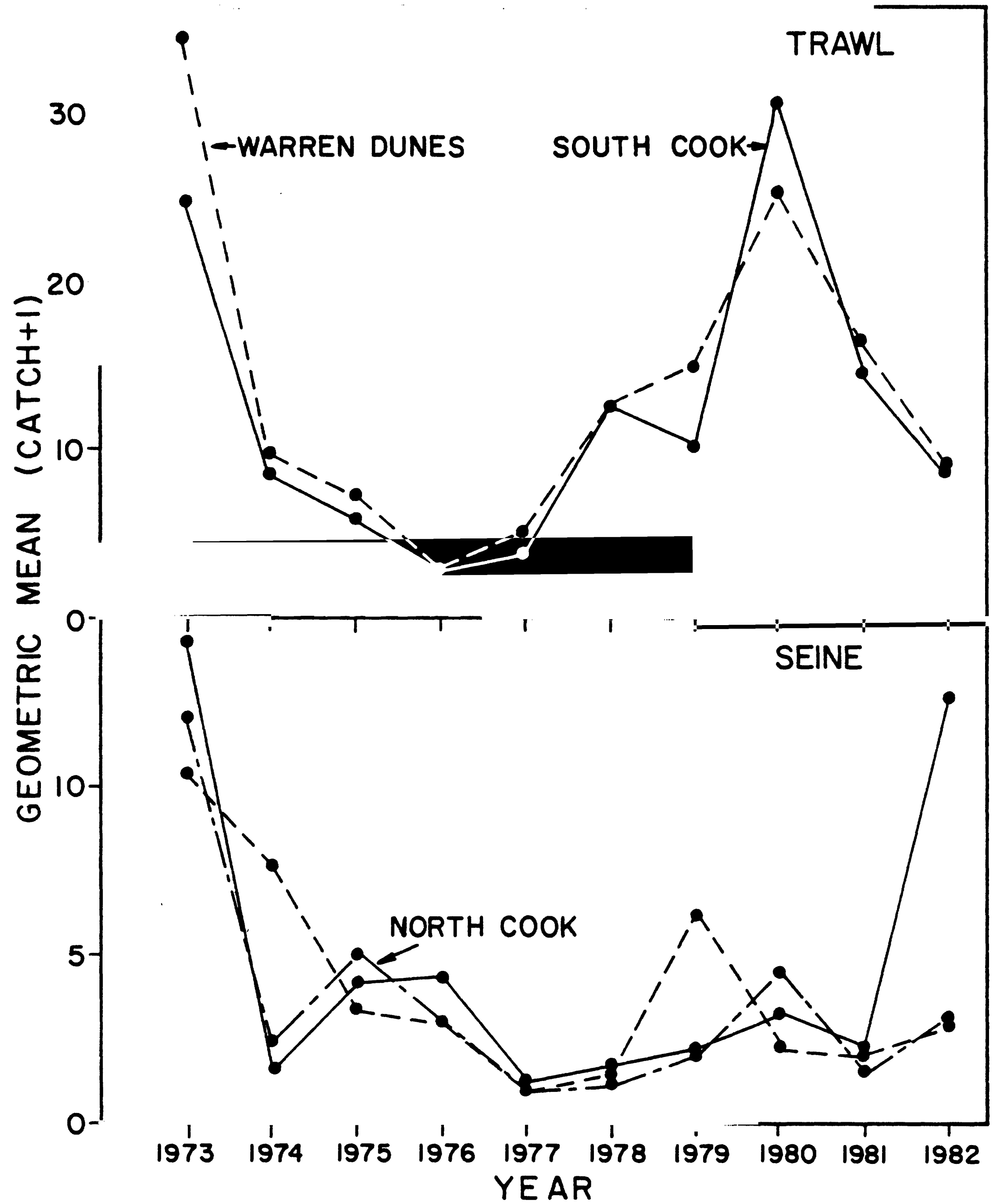


Fig. 6. Yearly geometric mean number of rainbow smelt caught by standard series trawling and seining in the study areas of southeastern Lake Michigan. The Cook Plant began operation in 1975.

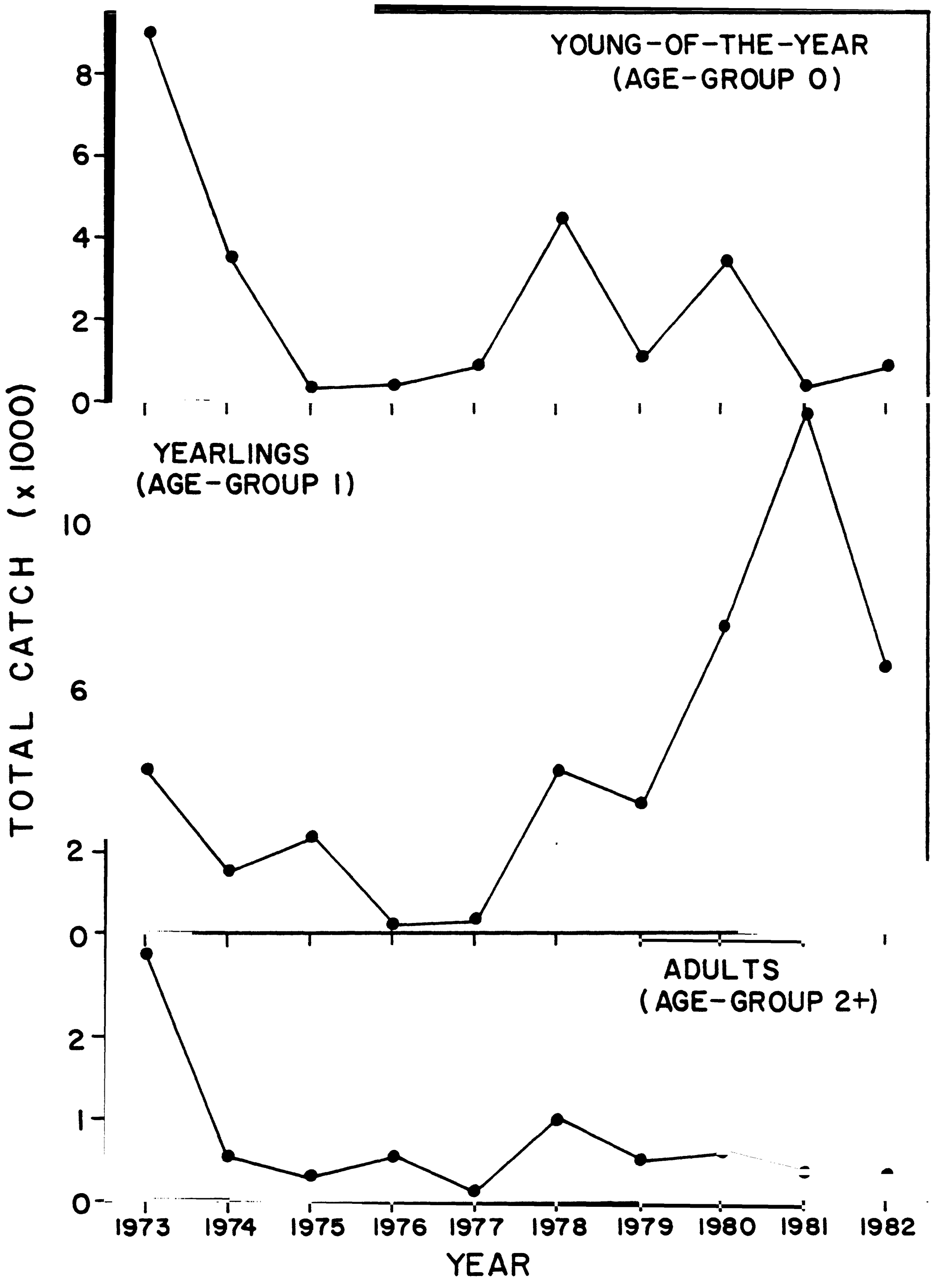


Fig. 7. Yearly total catch of three age-groups of rainbow smelt. Fish were caught from April to October by standard series netting in Cook Plant study areas, southeastern Lake Michigan.

Spottail shiners start moving shoreward in March. In spring they are distributed from shore to 9 m. From June to August, when spawning occurs, fish are distributed from <6 m to shore. During fall they move away from shore.

Past analyses have shown most yearly changes in spottail shiner catches were the result of year-class variability (Jude et al. 1979, Tesar et al. 1985). Catches in the two study areas were generally similar. Plant operation was not identified as a cause for catch differences because (1) year-class variability overshadowed other differences, (2) catches between areas or among seining stations were not significantly different, and (3) during operational years, catch changes occurred simultaneously in both study areas. However, there was one exception. Examination of ANOVAs applied to all 10-yr of data gave similar conclusions, no plant effects, regarding gill net and seine catches (Tables 13-16). However, trawl data show a significantly larger catch at Warren Dunes than at the Cook area (Tables 16-18). This difference has been consistent during all operational years; during preoperational years, catches were larger in the Cook area (Fig. 8). Causes for this apparent plant effect may be that either impingement mortality is substantial enough to depress spottail shiner numbers at the plant site or spottail shiners are avoiding the site during operation. While gill net catches were larger at Warren Dunes than at the Cook area, this difference was not significant enough to corroborate the trawl results (Table 16).

Although spottail shiner catch differences were small compared to other abundant species, an examination of age-group catches revealed year-to-year changes in abundance of all three age-groups (Fig. 9). These changes are the result of year-class variability in the spottail shiner population. Very

Table 13. Analysis of variance summary for log(catch + 1) of spottail shiners. Fish were gillnetted from April to September, 1973-1982 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df | Mean square | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 9 | 2.2254 | 25.5203 | <0.0001** |
| Month | 5 | 4.5078 | 51.6944 | <0.0001** |
| Area | 1 | 0.2142 | 2.4559 | 0.1241 |
| Depth | 1 | 2.7506 | 31.5432 | <0.0001** |
| Time | 1 | 49.9748 | 573.0938 | <0.0001** |
| Y x M | 45 | 1.5398 | 17.6577 | <0.0001** |
| Y x A | 9 | 0.0674 | 0.7732 | 0.6414 |
| M x A | 5 | 0.2231 | 2.5589 | 0.0403 |
| Y x D | 9 | 0.1314 | 1.5068 | 0.1748 |
| M x D | 5 | 0.5404 | 6.1975 | 0.0002** |
| A x D | 1 | 0.6219 | 7.1314 | 0.0105 |
| Y x T | 9 | 0.7208 | 8.2658 | <0.0001** |
| M x T | 5 | 0.9025 | 10.3501 | <0.0001** |
| A x T | 1 | 0.5191 | 5.9528 | 0.0187 |
| D x T | 1 | 6.1667 | 70.7173 | <0.0001** |
| Y x M x A | 45 | 0.3631 | 4.1636 | <0.0001** |
| Y x M x D | 45 | 0.2855 | 3.2739 | 0.0001** |
| Y x A x D | 9 | 0.0578 | 0.6627 | 0.7375 |
| M x A x D | 5 | 0.0879 | 1.0082 | 0.4240 |
| Y x M x T | 45 | 0.8237 | 9.4460 | <0.0001** |
| Y x A x T | 9 | 0.3086 | 3.5385 | 0.0022* |
| M x A x T | 5 | 0.1371 | 1.5722 | 0.1873 |
| Y x D x T | 9 | 0.0574 | 0.6587 | 0.7410 |
| M x D x T | 5 | 0.2164 | 2.4810 | 0.0456 |
| A x D x T | 1 | 0.0075 | 0.0861 | 0.7705 |
| Y x M x A x D | 45 | 0.0969 | 1.1107 | 0.3631 |
| Y x M x A x T | 45 | 0.1926 | 2.2090 | 0.0045* |
| Y x M x D x T | 45 | 0.1730 | 1.9843 | 0.0118 |
| Y x A x D x T | 9 | 0.0838 | 0.9606 | 0.4844 |
| M x A x D x T | 5 | 0.1268 | 1.4538 | 0.2238 |
| Y x M x A x D x T§ | 45 | 0.0872 | | |

** Highly significant (P < 0.001).
* Significant (P < 0.01).
§ The Y x M x A x D x T interaction is assumed to be zero and its mean square treated as the within cell error mean square.

Table 14. Analysis of variance summary for log(catch + 1) of spottail shiners. Fish were gillnetted from April to September, 1975-1981 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df | Mean square | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 6 | 4.6272 | 45.5188 | <0.0001** |
| Month | 5 | 4.2687 | 41.9926 | <0.0001** |
| Area | 2 | 0.0987 | 0.9707 | 0.3847 |
| Depth | 1 | 4.0175 | 39.5217 | <0.0001** |
| Time | 1 | 45.6024 | 448.6035 | <0.0001** |
| Y x M | 30 | 2.4631 | 24.2298 | <0.0001** |
| Y x A | 12 | 0.1393 | 1.3704 | 0.2054 |
| M x A | 10 | 0.1113 | 1.0948 | 0.3808 |
| Y x D | 6 | 0.1750 | 1.7211 | 0.1316 |
| M x D | 5 | 0.7599 | 7.4758 | <0.0001** |
| A x D | 2 | 0.2786 | 2.7408 | 0.0726 |
| Y x T | 6 | 1.0771 | 10.5961 | <0.0001** |
| M x T | 5 | 0.6414 | 6.3098 | 0.0001** |
| A x T | 2 | 0.2163 | 2.1280 | 0.1280 |
| D x T | 1 | 5.4935 | 54.0409 | <0.0001** |
| Y x M x A | 60 | 0.1384 | 1.3617 | 0.1174 |
| Y x M x D | 30 | 0.2766 | 2.7213 | 0.0005** |
| Y x A x D | 12 | 0.0755 | 0.7431 | 0.7042 |
| M x A x D | 10 | 0.1734 | 1.7055 | 0.1004 |
| Y x M x T | 30 | 1.5253 | 15.0045 | <0.0001** |
| Y x A x T | 12 | 0.0913 | 0.8980 | 0.5539 |
| M x A x T | 10 | 0.2200 | 2.1641 | 0.0326 |
| Y x D x T | 6 | 0.0462 | 0.4549 | 0.8387 |
| M x D x T | 5 | 0.1252 | 1.2314 | 0.3057 |
| A x D x T | 2 | 0.2349 | 2.3107 | 0.1080 |
| Y x M x A x D | 60 | 0.0913 | 0.8980 | 0.6609 |
| Y x M x A x T | 60 | 0.1642 | 1.6155 | 0.0328 |
| Y x M x D x T | 30 | 0.1966 | 1.9343 | 0.0150 |
| Y x A x D x T | 12 | 0.0522 | 0.5132 | 0.8981 |
| M x A x D x T | 10 | 0.0609 | 0.5988 | 0.8085 |
| Y x M x A x D x T§ | 60 | 0.1017 | | |

** Highly significant (P < 0.001).
§ The Y x M x A x D x T interaction is assumed to be zero and its mean square treated as the within cell error mean square.

Table 15. Analysis of variance summary for log(catch + 1) of spottail shiners. Fish were seined from April to October, 1973-1982 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df# | Adjusted mean square† | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 9 | 2.3925 | 13.1433 | <0.0001** |
| Month | 6 | 37.7703 | 207.4906 | <0.0001** |
| Station | 2 | 0.4511 | 2.4779 | 0.0851 |
| Time | 1 | 0.1050 | 0.5765 | 0.4481 |
| Y x M | 54 | 3.4497 | 18.9508 | <0.0001** |
| Y x S | 18 | 0.5129 | 2.8175 | 0.0001** |
| M x S | 12 | 0.8149 | 4.4768 | <0.0001** |
| Y x T | 9 | 1.6104 | 8.8469 | <0.0001** |
| M x T | 6 | 4.6833 | 25.7278 | <0.0001** |
| S x T | 2 | 0.1171 | 0.6430 | 0.5262 |
| Y x M x S | 108 | 0.3892 | 2.1382 | <0.0001** |
| Y x M x T | 54 | 1.9869 | 10.9149 | <0.0001** |
| Y x S x T | 18 | 0.3291 | 1.8077 | 0.0224 |
| M x S x T | 12 | 0.4791 | 2.6322 | 0.0021* |
| Y x M x S x T | 108 | 0.4260 | 2.3400 | <0.0001** |
| Within cell error | 419 | 0.1820 | | |

# One degree of freedom was subtracted from the error term to correct for one missing observation where the cell mean was substituted.
† Mean squares were multiplied by harmonic mean cell size/maximum cell size (nh/n = 0.9976) to correct for one missing observation where the cell mean was substituted.
** Highly significant (P < 0.001).
* Significant (P < 0.01).

Table 16. Geometric mean number (+ 1) of spottail shiners caught by trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan. NC = north Cook, SC south Cook, WD = Warren Dunes, D = day, N = night, station A = 1 m north Cook, B = 1 m south Cook, F = 1 m Warren Dunes, C = 6 m south Cook, D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes, R = 6 m north Cook.

| Year | | | | | | | | | | Month | | | | | | | Area | | | Depth | | Time | | Station | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | Ap | Ma | Ju | Ju | Au | Se | Oc | NC | SC | WD | 6m | 9m | D | N | A | B | F | C | D | G | H | R |
| Trawl (1973-1982 standard series data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | 7 | 7 | 10 | 11 | 8 | 19 | 23 | 11 | 8 | 6 | 16 | 14 | 5 | 8 | 13 | 23 | | 10 | 11 | 13 | 9 | 5 | 23 | | | | | | | | |
| Trawl (1975-1981 data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 8 | 10 | 11 | 7 | 20 | 21 | 11 | | 5 | 16 | 23 | 4 | 7 | 15 | 31 | | | | | | 5 | 28 | | | | 14 | 9 | 16 | 10 | 11 |
| Gill net (1973-1982 standard series data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 18 | 14 | 8 | 15 | 6 | 5 | 19 | 15 | 17 | 14 | 7 | 22 | 24 | 11 | 8 | 9 | | | 11 | 12 | 14 | 10 | 6 | 25 | | | | | | | | |
| Gill net (1975-1981 data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 7 | 14 | 6 | 4 | 18 | 17 | 16 | | 5 | 20 | 16 | 11 | 7 | 9 | | 10 | 10 | 11 | 13 | 8 | 5 | 21 | | | | | | | | |
| Seine (1973-1982 standard series data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 22 | 28 | 24 | 21 | 21 | 18 | 26 | 27 | 12 | 8 | 4 | 18 | 97 | 90 | 19 | 23 | 4 | | | | | | 19 | 20 | 20 | 21 | 18 | | | | | |

Table 17. Analysis of variance summary for log(catch + 1) of spottail shiners. Fish were trawled from April to October, 1973-1982 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df# | Adjusted mean square† | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 9 | 3.3072 | 58.9606 | <0.0001** |
| Month | 6 | 9.6534 | 172.1022 | <0.0001** |
| Area | 1 | 0.9022 | 16.0845 | 0.0001** |
| Depth | 1 | 9.9250 | 176.9433 | <0.0001** |
| Time | 1 | 125.8726 | 2244.0649 | <0.0001** |
| Y x M | 54 | 3.1481 | 56.1240 | <0.0001** |
| Y x A | 9 | 0.2186 | 3.8964 | 0.0001** |
| M x A | 6 | 1.1779 | 20.9996 | <0.0001** |
| Y x D | 9 | 0.5069 | 9.0365 | <0.0001** |
| M x D | 6 | 1.3579 | 24.2090 | <0.0001** |
| A x D | 1 | 0.1247 | 2.2230 | 0.1365 |
| Y x T | 9 | 1.2216 | 21.7785 | <0.0001** |
| M x T | 6 | 3.1296 | 55.7953 | <0.0001** |
| A x T | 1 | 1.5805 | 28.1766 | <0.0001** |
| D x T | 1 | 11.8716 | 211.6472 | <0.0001** |
| Y x M x A | 54 | 0.3415 | 6.0885 | <0.0001** |
| Y x M x D | 54 | 0.3530 | 6.2925 | <0.0001** |
| Y x A x D | 9 | 0.1895 | 3.3790 | 0.0005** |
| M x A x D | 6 | 0.3187 | 5.6811 | <0.0001** |
| Y x M x T | 54 | 1.4439 | 25.7418 | <0.0001** |
| Y x A x T | 9 | 0.3800 | 6.7748 | <0.0001** |
| M x A x T | 6 | 0.5436 | 9.6908 | <0.0001** |
| Y x D x T | 9 | 0.6082 | 10.8422 | <0.0001** |
| M x D x T | 6 | 0.4724 | 8.4219 | <0.0001** |
| A x D x T | 1 | 0.1267 | 2.2580 | 0.1335 |
| Y x M x A x D | 54 | 0.1801 | 3.2101 | <0.0001** |
| Y x M x A x T | 54 | 0.2827 | 5.0406 | <0.0001** |
| Y x M x D x T | 54 | 0.3663 | 6.5312 | <0.0001** |
| Y x A x D x T | 9 | 0.1646 | 2.9349 | 0.0021* |
| M x A x D x T | 6 | 0.3328 | 5.9327 | <0.0001** |
| Y x M x A x D x T | 54 | 0.1528 | 2.7238 | <0.0001** |
| Within cell error | 558 | 0.0561 | | |

\# Two degrees of freedom were subtracted from the error term to correct for two missing observations where the cell means were substituted.

† Mean squares were multiplied by harmonic mean cell size/maximum cell size (nh/n = 0.9964) to correct for two missing observations where the cell means were substituted.

** Highly significant (P < 0.001).

* Significant (P < 0.01).

Table 18. Analysis of variance summary for log(catch + 1) of spottail shiners. Fish were trawled from April to October, 1975-1981 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df | Mean square | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 6 | 4.5744 | 69.3414 | <0.0001** |
| Month | 6 | 15.3860 | 233.2313 | <0.0001** |
| Station | 4 | 2.2719 | 34.4397 | <0.0001** |
| Time | 1 | 139.1763 | 2109.7324 | <0.0001** |
| Y x M | 36 | 3.8041 | 57.6657 | <0.0001** |
| Y x S | 24 | 0.2598 | 3.9383 | <0.0001** |
| M x S | 24 | 0.7703 | 11.6775 | <0.0001** |
| Y x T | 6 | 1.2773 | 19.3622 | <0.0001** |
| M x T | 6 | 2.4910 | 37.7598 | <0.0001** |
| S x T | 4 | 2.2202 | 33.6547 | <0.0001** |
| Y x M x S | 144 | 0.2285 | 3.4645 | <0.0001** |
| Y x M x T | 36 | 1.8332 | 27.7890 | <0.0001** |
| Y x S x T | 24 | 0.2438 | 3.6964 | <0.0001** |
| M x S x T | 24 | 0.3459 | 5.2429 | <0.0001** |
| Y x M x S x T | 144 | 0.2499 | 3.7885 | <0.0001** |
| Within cell error | 490 | 0.0660 | | |

** Highly significant (P < 0.001).

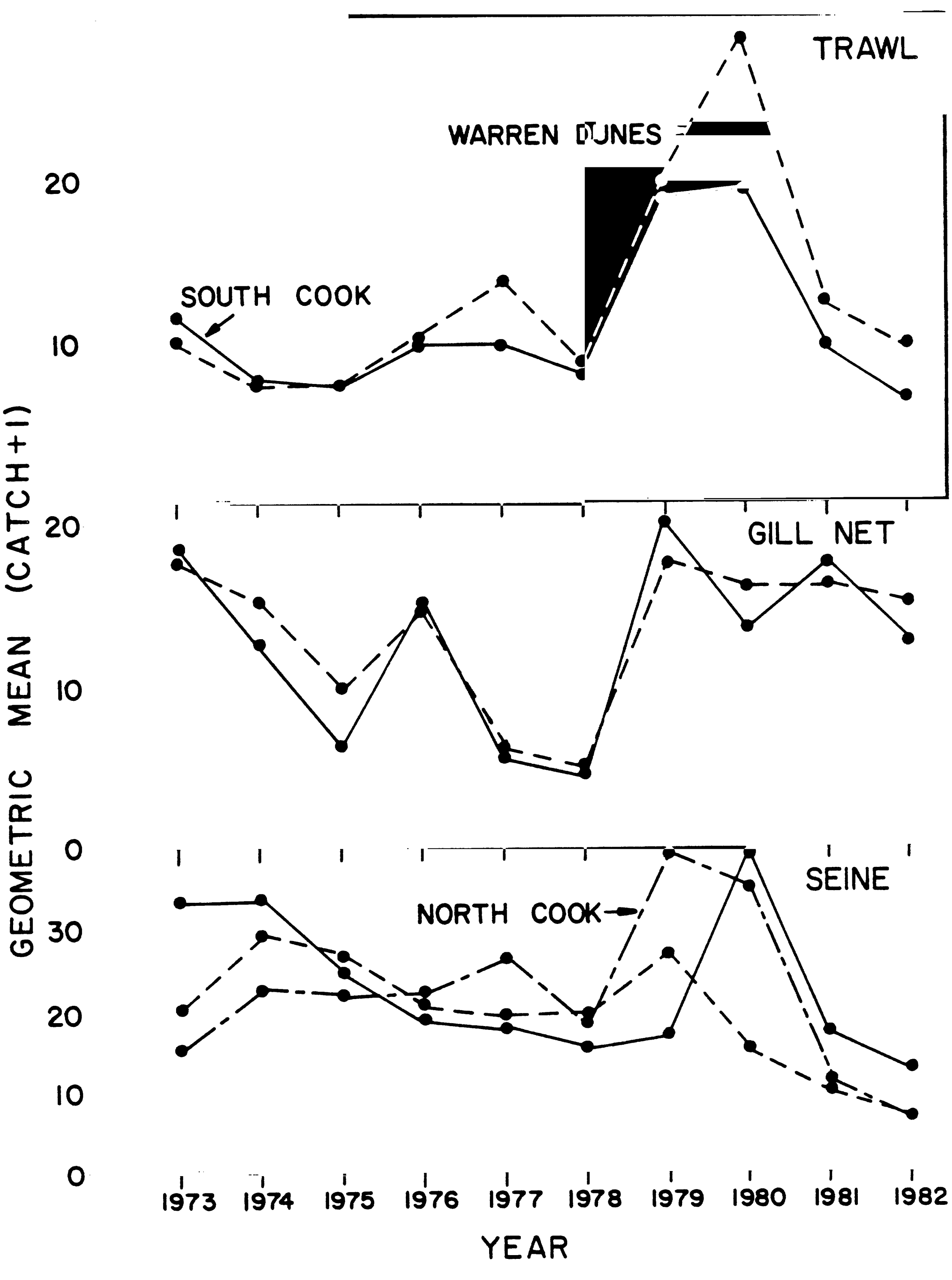


Fig. 8. Yearly geometric mean number of spottail shiners caught by standard series trawling, gillnetting, and seining in the study areas of southeastern Lake Michigan. The Cook Plant began operation in 1975.

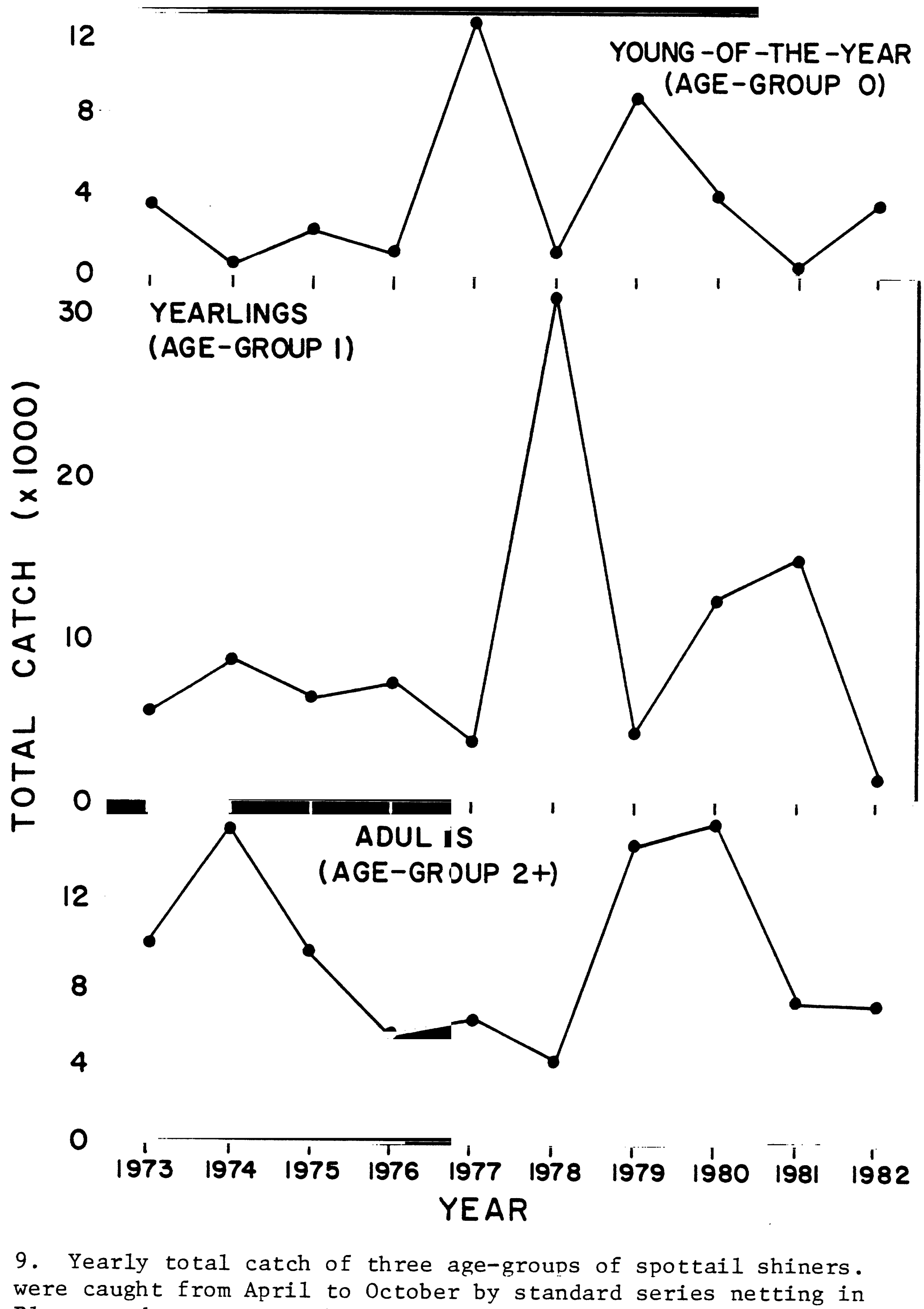


Fig. 9. Yearly total catch of three age-groups of spottail shiners. Fish were caught from April to October by standard series netting in Cook Plant study areas, southeastern Lake Michigan.

strong year classes were produced in 1977 and 1979. Additionally, abundance of yearlings was strongly correlated with the previous year's abundance of young-of-the-year (Spearman's rank correlation coefficient = 0.92; $P<0.05$).

Trout-perch

Trout-perch overwinter at depths from 18 to 45 m in southeastern Lake Michigan (Wells 1968). During spring, fish move shoreward and remain at 6 to 20 m during summer. The species prefers cool water, and it tends to follow movement of the thermocline in summer. Spawning can occur from May to September. During fall, fish move away from shore. Trout-perch move shoreward at night; however, few move into 1-m depths.

Yearly trout-perch catches varied almost 4 fold from 1973 to 1979. The catch of 3,122 fish in 1980 was the third-highest during the 10 yr, while the 1981 catch of 1,608 fish was somewhat below the 10-yr average of 2,103 fish. In contrast to these fluctuations, the 1982 catch of 280 fish was only 14% of the 10-yr average. Most of the decline in 1982 occurred in trawl and gill net catches.

The 1982 catch decline could be the result of water temperature. Because most trout-perch were trawled and gillnetted from June to September, temperatures encountered while sampling during these months substantially affect trout-perch catches as the species follows the cooler water of the metalimnion. During July to September 1982, water temperatures were generally higher than 21°C during trawling and gillnetting. Only in September at 9 m were temperatures less than 21°C. Trout-perch were probably distributed in cooler water deeper than 9 m. Thus a coincidence of warm water with sampling dates in summer 1982 contributed to a small yearly catch of trout-perch.

Another possible cause for the 1982 trout-perch decline may be an interaction with yellow perch. Yellow perch adults, which are predators of trout-perch, increased substantially in 1981 and especially in 1982. The yellow perch population may have reached a level where predation has substantially reduced the trout-perch population.

Past analyses of preoperational catch data have identified the seasonal migration, nocturnal inshore movement, and cool-water preference of trout-perch in the study areas (Jude et al. 1979). Changes in trout-perch distribution associated with movements of the thermocline cause substantial catch variation which complicates the identification of plant effects. Analyses of 1973 to 1979 data did not establish any changes in abundance resulting from plant operation (Tesar et al. 1985). Trawl catches did show that trout-perch were significantly more abundant at Warren Dunes than at Cook in operational years.

Examination of ANOVAs applied to 1973-1982 gill net and seine catch data did not reveal any plant effects on trout-perch abundance in the study areas (Tables 19-23). Yearly trawl catches varied more than 7 fold, while yearly gill net and seine catches varied, respectively, 4 and 3 fold (Table 24). During the last 3 yr of the study, seine catches at Warren Dunes were smaller than at the north Cook station, and ANOVA established a significant difference between station catches. Plant operation was not considered a cause for this difference. Trawl data, however, continued to show a significantly greater catch at Warren Dunes than in the Cook area (Fig. 10). This difference may be a result of plant operation. Substantial numbers of trout-perch were impinged, and this mortality may have depressed the species in the Cook area.

Table 19. Analysis of variance summary for log(catch + 1) of trout-perch. Fish were trawled from June to October, 1973-1982 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df# | Adjusted mean square† | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 9 | 6.6108 | 131.4549 | <0.0001** |
| Month | 4 | 4.4914 | 89.3113 | <0.0001** |
| Area | 1 | 2.0530 | 40.8237 | <0.0001** |
| Depth | 1 | 2.2426 | 44.5935 | <0.0001** |
| Time | 1 | 96.6491 | 1921.8606 | <0.0001** |
| Y x M | 36 | 1.6536 | 32.8818 | <0.0001** |
| Y x A | 9 | 0.1481 | 2.9441 | 0.0021* |
| M x A | 4 | 0.3964 | 7.8822 | <0.0001** |
| Y x D | 9 | 0.5306 | 10.5514 | <0.0001** |
| M x D | 4 | 1.3337 | 26.5210 | <0.0001** |
| A x D | 1 | 0.0007 | 0.0148 | 0.9034 |
| Y x T | 9 | 0.9851 | 19.5885 | <0.0001** |
| M x T | 4 | 2.0521 | 40.8051 | <0.0001** |
| A x T | 1 | 0.6402 | 12.7306 | 0.0004** |
| D x T | 1 | 1.4987 | 29.8024 | <0.0001** |
| Y x M x A | 36 | 0.2389 | 4.7512 | <0.0001** |
| Y x M x D | 36 | 0.3573 | 7.1042 | <0.0001** |
| Y x A x D | 9 | 0.1674 | 3.3283 | 0.0006** |
| M x A x D | 4 | 0.0853 | 1.6970 | 0.1498 |
| Y x M x T | 36 | 0.8752 | 17.4037 | <0.0001** |
| Y x A x T | 9 | 0.2639 | 5.2471 | <0.0001** |
| M x A x T | 4 | 0.8873 | 17.6439 | <0.0001** |
| Y x D x T | 9 | 0.8147 | 16.1998 | <0.0001** |
| M x D x T | 4 | 0.2422 | 4.8167 | 0.0008** |
| A x D x T | 1 | 0.3318 | 6.5984 | 0.0106 |
| Y x M x A x D | 36 | 0.1587 | 3.1557 | <0.0001** |
| Y x M x A x T | 36 | 0.1956 | 3.8903 | <0.0001** |
| Y x M x D x T | 36 | 0.2363 | 4.6994 | <0.0001** |
| Y x A x D x T | 9 | 0.0663 | 1.3184 | 0.2251 |
| M x A x D x T | 4 | 0.1831 | 3.6412 | 0.0063* |
| Y x M x A x D x T | 36 | 0.0891 | 1.7722 | 0.0049* |
| Within cell error | 399 | 0.0503 | | |

# One degree of freedom was subtracted from the error term to correct for one missing observation where the cell mean was substituted.
† Mean squares were multiplied by harmonic mean cell size/maximum cell size (nh/n = 0.9975) to correct for one missing observation where the cell mean was substituted.
** Highly significant (P < 0.001).
* Significant (P < 0.01).

Table 20. Analysis of variance summary for log(catch + 1) of trout-perch. Fish were trawled from June to October, 1975-1981 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df | Mean square | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 6 | 3.1627 | 65.3699 | <0.0001** |
| Month | 4 | 6.1522 | 127.1609 | <0.0001** |
| Station | 4 | 0.9617 | 19.8778 | <0.0001** |
| Time | 1 | 107.7190 | 2226.4712 | <0.0001** |
| Y x M | 24 | 2.4836 | 51.3352 | <0.0001** |
| Y x S | 24 | 0.2435 | 5.0335 | <0.0001** |
| M x S | 16 | 0.4149 | 8.5763 | <0.0001** |
| Y x T | 6 | 1.4025 | 28.9883 | <0.0001** |
| M x T | 4 | 2.6762 | 55.3156 | <0.0001** |
| S x T | 4 | 0.6790 | 14.0351 | <0.0001** |
| Y x M x S | 96 | 0.2340 | 4.8368 | <0.0001** |
| Y x M x T | 24 | 0.9661 | 19.9684 | <0.0001** |
| Y x S x T | 24 | 0.2291 | 4.7352 | <0.0001** |
| M x S x T | 16 | 0.2776 | 5.7376 | <0.0001** |
| Y x M x S x T | 96 | 0.1987 | 4.1076 | <0.0001** |
| Within cell error | 350 | 0.0484 | | |

** Highly significant (P < 0.001).

Table 21. Analysis of variance summary for log(catch + 1) of trout-perch. Fish were gillnetted from May to September, 1973-1982 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df | Mean square | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 9 | 0.4830 | 9.8550 | <0.0001** |
| Month | 4 | 0.3649 | 7.4459 | 0.0002** |
| Area | 1 | 0.0058 | 0.1187 | 0.7325 |
| Depth | 1 | 0.4568 | 9.3212 | 0.0042* |
| Y x M | 36 | 0.4451 | 9.0828 | <0.0001** |
| Y x A | 9 | 0.1771 | 3.6131 | 0.0027* |
| M x A | 4 | 0.1327 | 2.7069 | 0.0454 |
| Y x D | 9 | 0.0763 | 1.5560 | 0.1662 |
| M x D | 4 | 0.1662 | 3.3920 | 0.0187 |
| A x D | 1 | 0.0012 | 0.0241 | 0.8775 |
| Y x M x A | 36 | 0.0795 | 1.6220 | 0.0758 |
| Y x M x D | 36 | 0.1141 | 2.3286 | 0.0065* |
| Y x A x D | 9 | 0.1086 | 2.2160 | 0.0439 |
| M x A x D | 4 | 0.0594 | 1.2123 | 0.3226 |
| Y x M x A x D§ | 36 | 0.0490 | | |

** Highly significant (P < 0.001).
* Significant (P < 0.01).
§ The Y x M x A x D interaction is assumed to be zero and its mean square treated as the within cell error mean square.

Table 22. Analysis of variance summary for log(catch + 1) of trout-perch. Fish were gillnetted from May to September, 1975-1981 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df | Mean square | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 6 | 0.1136 | 2.4729 | 0.0364 |
| Month | 4 | 0.1134 | 2.4688 | 0.0572 |
| Area | 2 | 0.2075 | 4.5177 | 0.0159 |
| Depth | 1 | 0.4130 | 8.9916 | 0.0043* |
| Y x M | 24 | 0.6289 | 13.6920 | <0.0001** |
| Y x A | 12 | 0.1367 | 2.9769 | 0.0036* |
| M x A | 8 | 0.1089 | 2.3701 | 0.0308 |
| Y x D | 6 | 0.0874 | 1.9032 | 0.0995 |
| M x D | 4 | 0.0316 | 0.6879 | 0.6039 |
| A x D | 2 | 0.0423 | 0.9208 | 0.4051 |
| Y x M x A | 48 | 0.0873 | 1.9014 | 0.0140 |
| Y x M x D | 24 | 0.0950 | 2.0688 | 0.0160 |
| Y x A x D | 12 | 0.0987 | 2.1489 | 0.0307 |
| M x A x D | 8 | 0.0374 | 0.8150 | 0.5930 |
| Y x M x A x D§ | 48 | 0.0459 | | |

* Significant ($P < 0.01$).
** Highly significant ($P < 0.001$).
§ The Y x M x A x D interaction is assumed to be zero and its mean square treated as the within cell error mean square.

Table 23. Analysis of variance summary for log(catch + 1) of trout-perch. Fish were seined from April to October, 1973-1982 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df# | Adjusted mean square† | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 9 | 0.3988 | 11.4768 | <0.0001** |
| Month | 6 | 0.5940 | 17.0946 | <0.0001** |
| Station | 2 | 0.1786 | 5.1408 | 0.0066* |
| Y x M | 54 | 0.6690 | 19.2525 | <0.0001** |
| Y x S | 18 | 0.0498 | 1.4318 | 0.1190 |
| M x S | 12 | 0.1412 | 4.0636 | <0.0001** |
| Y x M x S | 108 | 0.0776 | 2.2323 | <0.0001** |
| Within cell error | 209 | 0.0347 | | |

# One degree of freedom was subtracted from the error term to correct for one missing observation where the cell mean was substituted.
† Mean squares were multiplied by harmonic mean cell size/maximum cell size (nh/n = 0.9953) to correct for one missing observation where the cell mean was substituted.
** Highly significant ($P < 0.001$).
* Significant ($P < 0.01$).

Table 24. Geometric mean number (+ 1) of trout-perch caught by trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan. NC = north Cook, SC = south Cook, WD = Warren Dunes, D = day, N = night, station A = 1 m north Cook, B = 1 m south Cook, F = 1 m Warren Dunes, C = 6 m south Cook, D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes, R = 6 m north Cook.

| Year | | | | | | | | | | Month | | | | | | | Area | | | Depth | | Time | | Station | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | Ap | Ma | Ju | Ju | Au | Se | Oc | NC | SC | WD | 6m | 9m | D | N | A | B | F | C | D | G | H | R |
| Trawl (1973-1982 standard series data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 15 | 5 | 4 | 6 | 9 | 14 | 7 | 13 | 6 | 2 | | | 6 | 13 | 5 | 5 | 7 | | 6 | 8 | 6 | 8 | 3 | 15 | | | | | | | | |
| Trawl (1975-1981 data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 4 | 6 | 8 | 13 | 7 | 11 | 5 | | | | 6 | 15 | 5 | 5 | 9 | | | | | | 3 | 18 | | | | 6 | 7 | 8 | 9 | 6 |
| Gill net (1973-1982 standard series data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | 4 | 3 | 4 | 3 | 3 | 4 | 3 | 3 | 1 | | 3 | 3 | 4 | 3 | 3 | | | 3 | 3 | 3 | 4 | | | | | | | | | | |
| Gill net (1975-1981 data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 3 | 4 | 4 | 3 | 3 | 3 | 3 | | | 3 | 3 | 4 | 3 | 3 | | 3 | 3 | 3 | 3 | 3 | | | | | | | | | | |
| Seine (1973-1982 standard series data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 1 | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 1 | | | | | | | | 2 | 2 | 2 | | | | | |

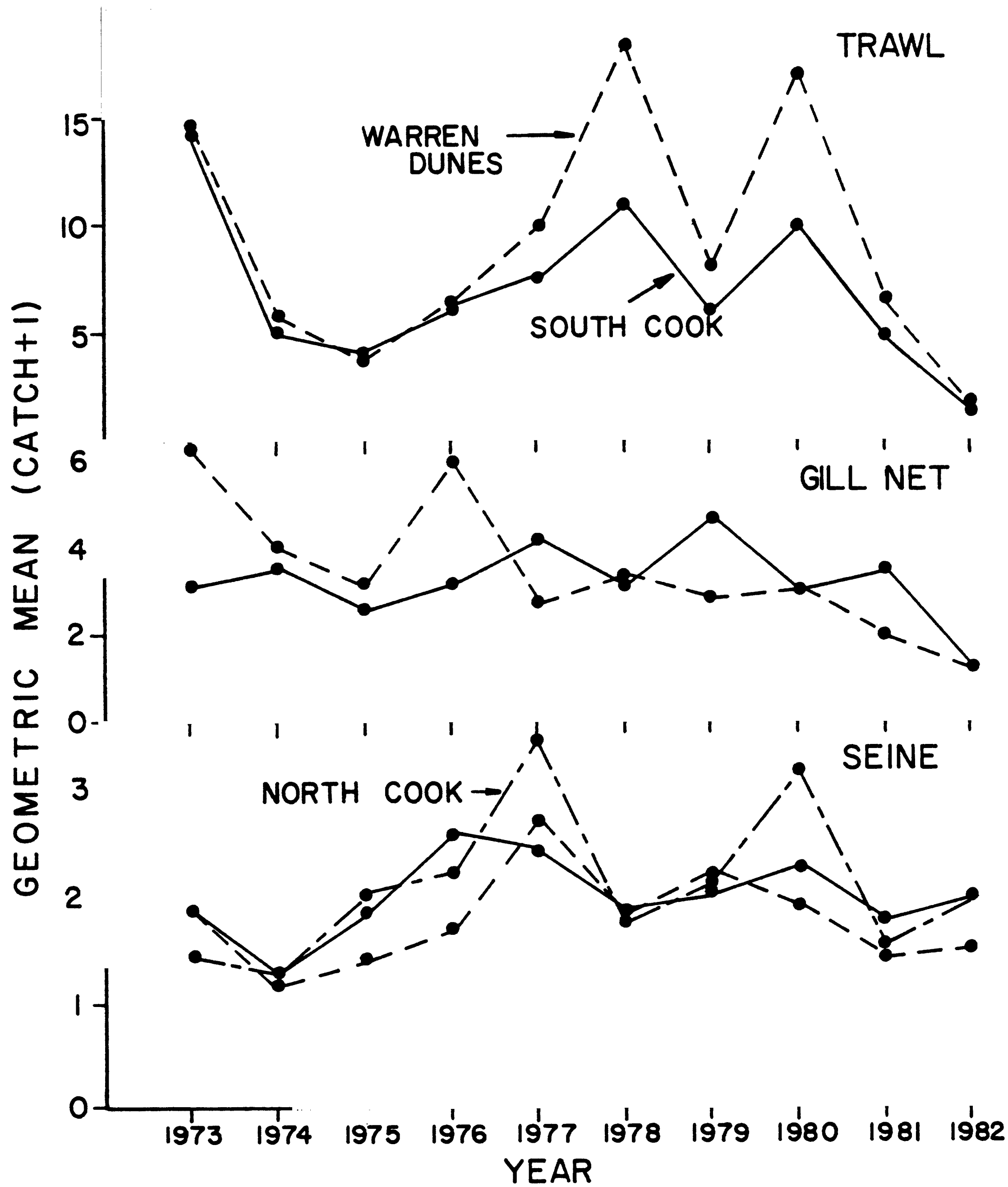


Fig. 10. Yearly geometric mean number of trout-perch caught by standard series trawling, gillnetting, and seining in the study areas of southeastern Lake Michigan. The Cook Plant began operation in 1975.

Division of catch data by trout-perch age-group showed considerable year-to-year fluctuation in abundance of all three age-groups (Fig. 11). Very few young-of-the-year were collected in the study areas. Undoubtedly, yearly variation in water temperature contributed to abundance fluctuations. The extreme fluctuations in yearling abundance suggest that year-class strength of this species also varies considerably.

Yellow Perch

Yellow perch in Lake Michigan overwinter at depths from 9 to 37 m (Wells 1968). In spring, fish move shoreward to 5-13-m depths and spawn from late May to early June (Dorr 1982). During late summer and fall, fish move back to deeper water. The species is day-active and nocturnally inactive with pre-sunset and post-sunrise activity peaks (Helfman 1979). Also, fish move toward shore at sunset and away from shore at sunrise. Yearlings and young-of-the-year in summer are at depths from 1 to 6 m.

From 1973 to 1979, yearly yellow perch catches averaged about 3,500 fish per year with a range from almost 4,700 fish in 1979 to almost 1,600 fish in 1978. During 1980-1982, an exceptional increase occurred, and the yearly catch averaged almost 19,000 fish. With this increase, the average catch over the 10-yr period increased to 6,100 fish per year. Catches in all three gear, especially trawls, increased during 1980-1982.

Preoperational catch data revealed considerable variation in yellow perch abundance and distribution (Jude et al. 1979). Most of this variation resulted from diel and seasonal movements, year-class strength, and temperature. Analyses of seine and trawl catches from 1973 to 1979 identified no plant effects on yellow perch abundance and distribution (Tesar et al. 1985). Gill net catches did reveal a tendency for greater perch abundance at the Cook Plant,

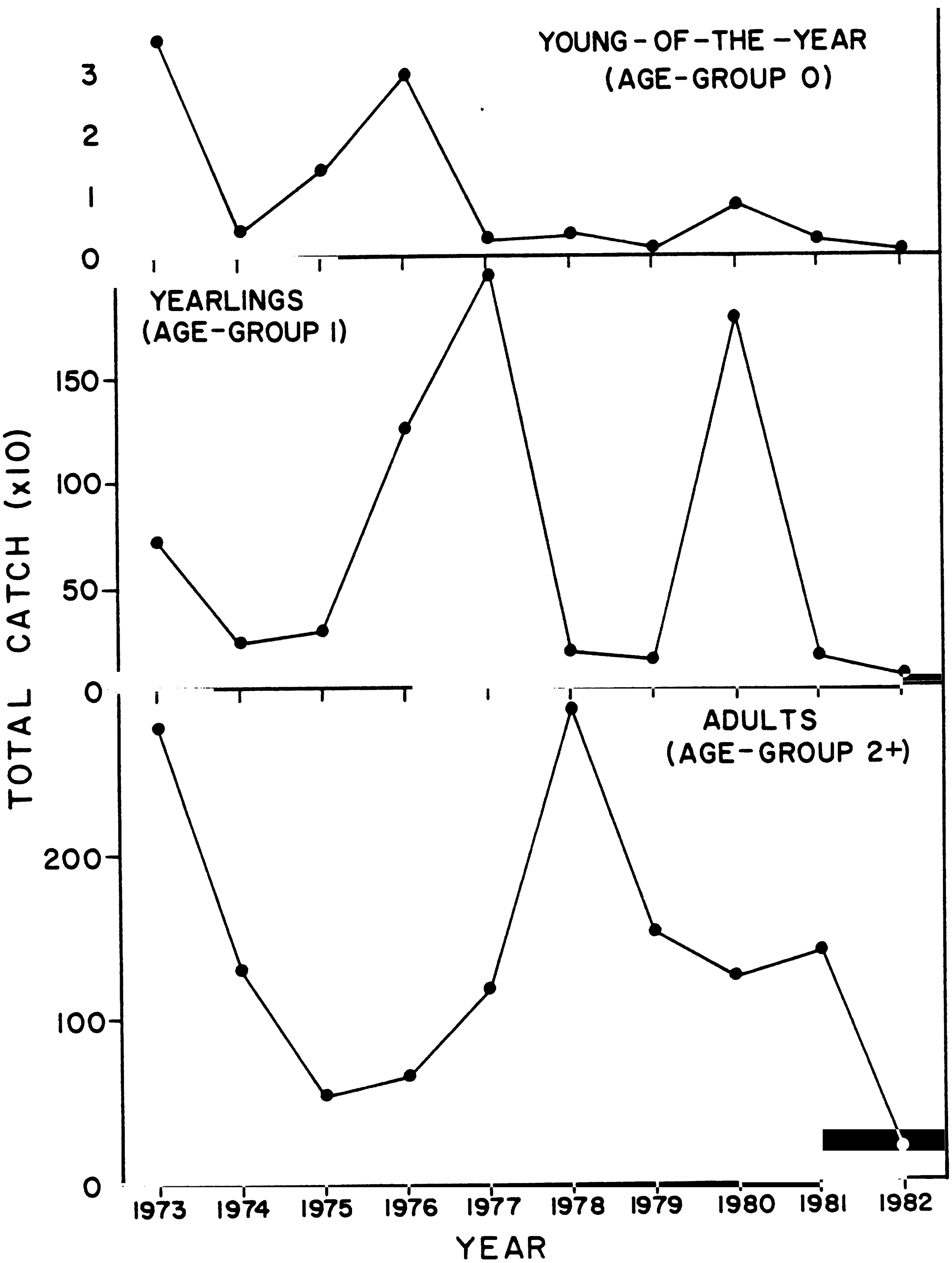


Fig. 11. Yearly total catch of three age-groups of trout-perch. Fish were caught from April to October by standard series netting in Cook Plant study areas, southeastern Lake Michigan.

apparently an attraction of large fish to the plant's riprap and discharges. Divers confirmed that yellow perch were attracted to the riprap (Dorr and Jude 1980).

Analysis of ANOVA results using all 10 yr of seine data produced a similar conclusion as the previous analysis, that is, no plant effects (Table 25). Catches at all three seining stations showed similar year-to-year changes in abundance during operational years (Fig. 12). However, ANOVA results from the 10 yr of gill net and trawl data showed some changes from previous analyses without 1980-1982 data. Trawl data ANOVA showed a significantly greater catch at Warren Dunes than at Cook (Tables 26-28). This difference was primarily the result of substantially larger catches at Warren Dunes in 1980 and 1982 (Fig. 12). These large Warren Dunes catches suggest that plant operation may be decreasing abundance in the Cook area; however, most other operational years did not demonstrate this difference, and further, the catch at Cook in 1981 was larger than at Warren Dunes. Thus, results from trawl catches are ambiguous in identifying a plant effect. Results of ANOVA applied to gill net data from 1973 to 1982 show no significant difference in area catches (Tables 28-30). A larger catch at Warren Dunes than at Cook in 1982 reversed a trend of larger catches at Cook during most other operational years (Fig. 12). Consequently, the previous conclusion, drawn from 1973 to 1979 data, of a tendency for large yellow perch to be attracted to the plant's riprap and discharges is weakened when the 10-yr dataset is considered.

Abundances of all age-groups of yellow perch remained relatively unchanged from 1973 to 1979 (Fig. 13). In 1980, an extremely strong year class emerged. This year class returned in 1981, producing a record catch of yearlings, and again returned in 1982 as adults. In 1982, another strong year

Table 25. Analysis of variance summary for log(catch + 1) of yellow perch. Fish were seined from June to August, 1973-1982 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df# | Adjusted mean square† | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 9 | 3.4070 | 37.5711 | <0.0001** |
| Month | 2 | 21.0176 | 231.7715 | <0.0001** |
| Station | 2 | 0.2701 | 2.9790 | 0.0534 |
| Time | 1 | 0.2287 | 2.5218 | 0.1140 |
| Y x M | 18 | 4.5087 | 49.7195 | <0.0001** |
| Y x S | 18 | 0.2212 | 2.4393 | 0.0015* |
| M x S | 4 | 0.1967 | 2.1691 | 0.0743 |
| Y x T | 9 | 1.7952 | 19.7971 | <0.0001** |
| M x T | 2 | 0.0433 | 0.4770 | 0.6214 |
| S x T | 2 | 1.1957 | 13.1861 | <0.0001** |
| Y x M x S | 36 | 0.2794 | 3.0812 | <0.0001** |
| Y x M x T | 18 | 1.9124 | 21.0892 | <0.0001** |
| Y x S x T | 18 | 0.2185 | 2.4093 | 0.0018* |
| M x S x T | 4 | 0.2514 | 2.7727 | 0.0287 |
| Y x M x S x T | 36 | 0.2708 | 2.9860 | <0.0001** |
| Within cell error | 179 | 0.0907 | | |

# One degree of freedom was subtracted from the error term to correct for one missing observation where the cell mean was substituted.
† Mean squares were multiplied by harmonic mean cell size/maximum cell size (nh/n = 0.9945) to correct for one missing observation where the cell mean was substituted.
** Highly significant (P < 0.001).
* Significant (P < 0.01).

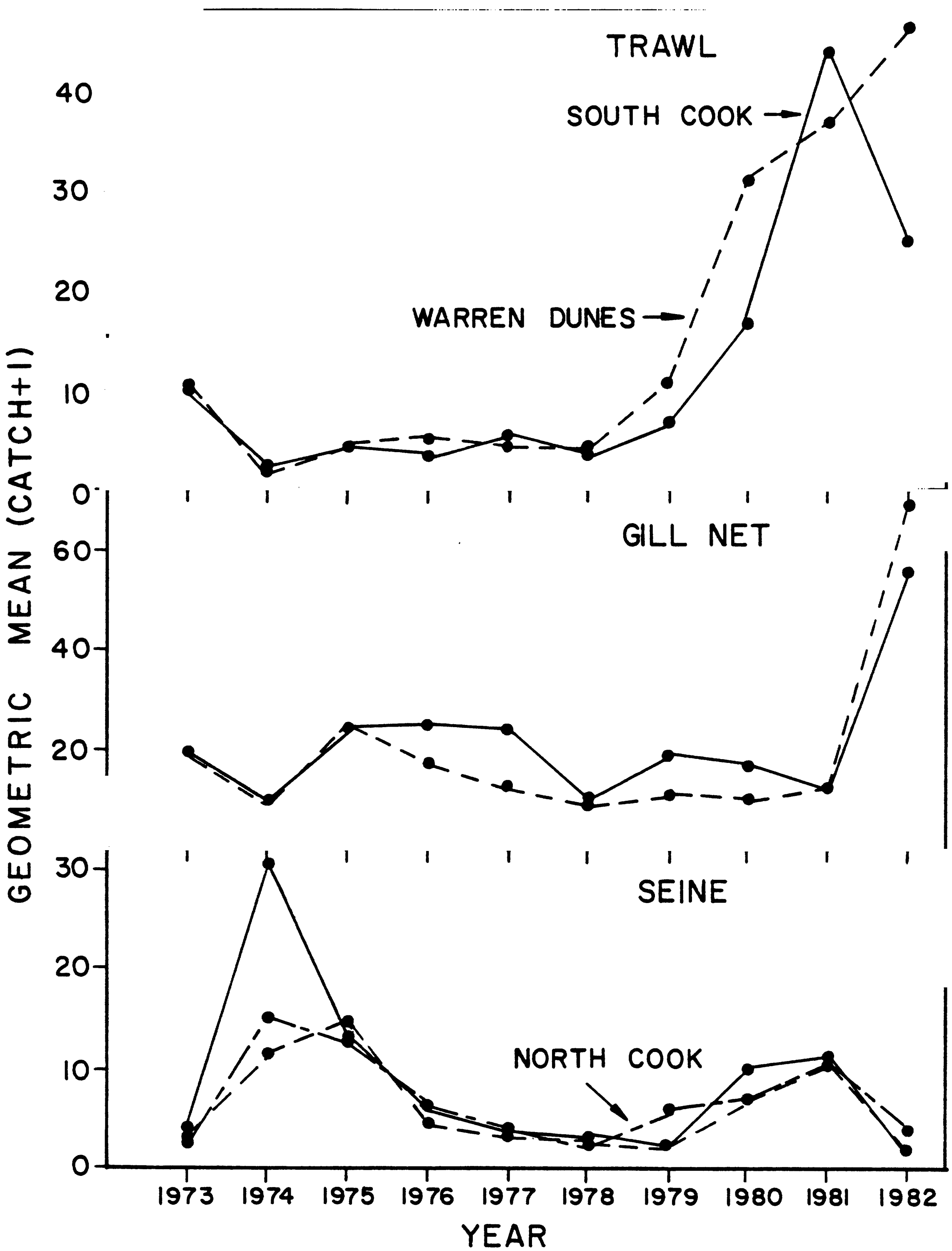


Fig. 12. Yearly geometric mean number of yellow perch caught by standard series trawling, gillnetting, and seining in the study areas of southeastern Lake Michigan. The Cook Plant began operation in 1975.

Table 26. Analysis of variance summary for log(catch + 1) of yellow perch. Fish were trawled from June to October, 1973-1982 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df# | Adjusted mean square† | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 9 | 15.3940 | 139.9261 | <0.0001** |
| Month | 4 | 6.8620 | 62.3731 | <0.0001** |
| Area | 1 | 1.1238 | 10.2149 | 0.0015* |
| Depth | 1 | 0.2400 | 2.1820 | 0.1404 |
| Time | 1 | 14.2213 | 129.2667 | <0.0001** |
| Y x M | 36 | 2.4151 | 21.9527 | <0.0001** |
| Y x A | 9 | 0.4380 | 3.9814 | 0.0001** |
| M x A | 4 | 0.2610 | 2.3723 | 0.0518 |
| Y x D | 9 | 0.3566 | 3.2411 | 0.0008** |
| M x D | 4 | 1.7211 | 15.6438 | <0.0001** |
| A x D | 1 | 0.0092 | 0.0836 | 0.7727 |
| Y x T | 9 | 0.4031 | 3.6638 | 0.0002** |
| M x T | 4 | 1.8336 | 16.6667 | <0.0001** |
| A x T | 1 | 0.1280 | 1.1633 | 0.2814 |
| D x T | 1 | 1.9049 | 17.3145 | <0.0001** |
| Y x M x A | 36 | 0.3141 | 2.8549 | <0.0001** |
| Y x M x D | 36 | 0.4084 | 3.7126 | <0.0001** |
| Y x A x D | 9 | 0.0960 | 0.8729 | 0.5495 |
| M x A x D | 4 | 0.1963 | 1.7841 | 0.1312 |
| Y x M x T | 36 | 1.6144 | 14.6747 | <0.0001** |
| Y x A x T | 9 | 0.1307 | 1.1880 | 0.3009 |
| M x A x T | 4 | 0.1335 | 1.2136 | 0.3044 |
| Y x D x T | 9 | 0.6735 | 6.1223 | <0.0001** |
| M x D x T | 4 | 0.4091 | 3.7186 | 0.0055* |
| A x D x T | 1 | 0.2662 | 2.4197 | 0.1206 |
| Y x M x A x D | 36 | 0.1819 | 1.6532 | 0.0121 |
| Y x M x A x T | 36 | 0.1926 | 1.7508 | 0.0058* |
| Y x M x D x T | 36 | 0.4494 | 4.0845 | <0.0001** |
| Y x A x D x T | 9 | 0.2044 | 1.8579 | 0.0567 |
| M x A x D x T | 4 | 0.2155 | 1.9585 | 0.1001 |
| Y x M x A x D x T | 36 | 0.1212 | 1.1015 | 0.3207 |
| Within cell error | 399 | 0.1100 | | |

# One degree of freedom was subtracted from the error term to correct for one missing observation where the cell mean was substituted.

† Mean squares were multiplied by harmonic mean cell size/maximum cell size (nh/n = 0.9975) to correct for one missing observation where the cell mean was substituted.

** Highly significant (P < 0.001).

* Significant (P < 0.01).

Table 27. Analysis of variance summary for log(catch + 1) of yellow perch. Fish were trawled from June to October, 1975-1981 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df | Mean square | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 6 | 15.6506 | 155.9466 | <0.0001** |
| Month | 4 | 7.1778 | 71.5212 | <0.0001** |
| Station | 4 | 0.8183 | 8.1541 | <0.0001** |
| Time | 1 | 20.1759 | 201.0379 | <0.0001** |
| Y x M | 24 | 3.5409 | 35.2830 | <0.0001** |
| Y x S | 24 | 0.2472 | 2.4628 | 0.0002** |
| M x S | 16 | 0.4582 | 4.5658 | <0.0001** |
| Y x T | 6 | 0.3053 | 3.0421 | 0.0065* |
| M x T | 4 | 1.6142 | 16.0847 | <0.0001** |
| S x T | 4 | 0.5391 | 5.3721 | 0.0003** |
| Y x M x S | 96 | 0.3099 | 3.0880 | <0.0001** |
| Y x M x T | 24 | 1.6383 | 16.3245 | <0.0001** |
| Y x S x T | 24 | 0.2339 | 2.3303 | 0.0005** |
| M x S x T | 16 | 0.2025 | 2.0177 | 0.0116 |
| Y x M x S x T | 96 | 0.2288 | 2.2799 | <0.0001** |
| Within cell error | 350 | 0.1004 | | |

** Highly significant (P < 0.001).
* Significant (P < 0.01).

Table 28. Geometric mean number (+ 1) of yellow perch caught by trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan. NC = north Cook, SC = south Cook, WD Warren Dunes, D = day, N = night, station A = 1 m north Cook, B = 1 m south Cook, F = 1 m Warren Dunes, C = 6 m south Cook, D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes, R = 6 m north Cook.

| Year | | | | | | | | | | Month | | | | | | | Area | | | Depth | | Time | | Station | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | Ap | Ma | Ju | Ju | Au | Se | Oc | NC | SC | WD | 6m | 9m | D | N | A | B | F | C | D | G | H | R |
| Trawl (1973-1982 standard series data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | 2 | 4 | 4 | 5 | 4 | 9 | 23 | 40 | 34 | | | 8 | 6 | 10 | 17 | 5 | | 8 | 9 | 9 | 8 | 6 | 12 | | | | | | | | |
| Trawl (1975-1981 data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 4 | 4 | 5 | 4 | 7 | 21 | 36 | | | | 7 | 6 | 9 | 17 | 4 | | | | | | 5 | 11 | | | | 8 | 7 | 9 | 9 | 6 |
| Gill net (1973-1982 standard series data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | 9 | 23 | 21 | 17 | 9 | 14 | 13 | 13 | 63 | | | 13 | 16 | 22 | 19 | | | 19 | 15 | 17 | 17 | 20 | 14 | | | | | | | | |
| Gill net (1975-1981 data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 24 | 22 | 16 | 10 | 14 | 13 | 12 | | | | 10 | 14 | 23 | 17 | | 15 | 17 | 13 | 15 | 16 | 17 | 14 | | | | | | | | |
| Seine (1973-1982 standard series data) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 17 | 14 | 5 | 4 | 3 | 3 | 8 | 11 | 2 | | | 3 | 17 | 3 | | | | | | | | 5 | 6 | 6 | 6 | 5 | | | | | |

Table 29. Analysis of variance summary for log(catch + 1) of yellow perch. Fish were gillnetted from June to September, 1973-1982 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df | Mean square | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 9 | 1.9385 | 26.8143 | <0.0001** |
| Month | 3 | 0.8440 | 11.6745 | <0.0001** |
| Area | 1 | 0.5175 | 7.1585 | 0.0125 |
| Depth | 1 | 0.0196 | 0.2705 | 0.6072 |
| Time | 1 | 1.6832 | 23.2826 | <0.0001** |
| Y x M | 27 | 1.2131 | 16.7795 | <0.0001** |
| Y x A | 9 | 0.1000 | 1.3836 | 0.2439 |
| M x A | 3 | 0.0648 | 0.8964 | 0.4558 |
| Y x D | 9 | 0.3271 | 4.5248 | 0.0011* |
| M x D | 3 | 1.4285 | 19.7591 | <0.0001** |
| A x D | 1 | 0.0398 | 0.5501 | 0.4647 |
| Y x T | 9 | 0.7385 | 10.2158 | <0.0001** |
| M x T | 3 | 0.6344 | 8.7748 | 0.0003** |
| A x T | 1 | 0.0171 | 0.2364 | 0.6307 |
| D x T | 1 | 0.9504 | 13.1465 | 0.0012* |
| Y x M x A | 27 | 0.1395 | 1.9300 | 0.0467 |
| Y x M x D | 27 | 0.4661 | 6.4467 | <0.0001** |
| Y x A x D | 9 | 0.0861 | 1.1907 | 0.3403 |
| M x A x D | 3 | 0.1236 | 1.7100 | 0.1885 |
| Y x M x T | 27 | 0.4902 | 6.7801 | <0.0001** |
| Y x A x T | 9 | 0.0709 | 0.9809 | 0.4774 |
| M x A x T | 3 | 0.0579 | 0.8014 | 0.5040 |
| Y x D x T | 9 | 0.0871 | 1.2052 | 0.3321 |
| M x D x T | 3 | 0.1739 | 2.4059 | 0.0892 |
| A x D x T | 1 | 0.0570 | 0.7882 | 0.3825 |
| Y x M x A x D | 27 | 0.0675 | 0.9338 | 0.5700 |
| Y x M x A x T | 27 | 0.1173 | 1.6226 | 0.1075 |
| Y x M x D x T | 27 | 0.1435 | 1.9852 | 0.0402 |
| Y x A x D x T | 9 | 0.1467 | 2.0289 | 0.0752 |
| M x A x D x T | 3 | 0.0938 | 1.2971 | 0.2956 |
| Y x M x A x D x T§ | 27 | 0.0723 | | |

** Highly significant (P < 0.001).
* Significant (P < 0.01).
§ The Y x M x A x D x T interaction is assumed to be zero and its mean square treated as the within cell error mean square.

Table 30. Analysis of variance summary for log(catch + 1) of yellow perch. Fish were gillnetted from June to September, 1975-1981 at Cook Plant study areas, southeastern Lake Michigan.

| Source of variation | df | Mean square | F-statistic | Attained significance |
|---|---|---|---|---|
| Year | 6 | 0.9205 | 11.9684 | <0.0001** |
| Month | 3 | 1.9956 | 25.9467 | <0.0001** |
| Area | 2 | 0.4145 | 5.3892 | 0.0090* |
| Depth | 1 | 0.0379 | 0.4929 | 0.4872 |
| Time | 1 | 0.3807 | 4.9504 | 0.0324 |
| Y x M | 18 | 1.3885 | 18.0527 | <0.0001** |
| Y x A | 12 | 0.0793 | 1.0311 | 0.4430 |
| M x A | 6 | 0.1581 | 2.0551 | 0.0833 |
| Y x D | 6 | 0.6416 | 8.3425 | <0.0001** |
| M x D | 3 | 1.7395 | 22.6165 | <0.0001** |
| A x D | 2 | 0.0132 | 0.1712 | 0.8434 |
| Y x T | 6 | 1.0048 | 13.0642 | <0.0001** |
| M x T | 3 | 0.3327 | 4.3259 | 0.0105 |
| A x T | 2 | 0.0416 | 0.5413 | 0.5867 |
| D x T | 1 | 1.2053 | 15.6708 | 0.0003** |
| Y x M x A | 36 | 0.1291 | 1.6786 | 0.0624 |
| Y x M x D | 18 | 0.5966 | 7.7572 | <0.0001** |
| Y x A x D | 12 | 0.0774 | 1.0060 | 0.4635 |
| M x A x D | 6 | 0.1005 | 1.3073 | 0.2790 |
| Y x M x T | 18 | 0.9723 | 12.6422 | <0.0001** |
| Y x A x T | 12 | 0.1157 | 1.5046 | 0.1678 |
| M x A x T | 6 | 0.1480 | 1.9240 | 0.1034 |
| Y x D x T | 6 | 0.0802 | 1.0429 | 0.4143 |
| M x D x T | 3 | 0.0699 | 0.9083 | 0.4466 |
| A x D x T | 2 | 0.0936 | 1.2175 | 0.3079 |
| Y x M x A x D | 36 | 0.0682 | 0.8870 | 0.6396 |
| Y x M x A x T | 36 | 0.1271 | 1.6525 | 0.0683 |
| Y x M x D x T | 18 | 0.1831 | 2.3804 | 0.0131 |
| Y x A x D x T | 12 | 0.1301 | 1.6910 | 0.1103 |
| M x A x D x T | 6 | 0.0674 | 0.8768 | 0.5216 |
| Y x M x A x D x T§ | 36 | 0.0769 | | |

** Highly significant (P < 0.001).
* Significant (P < 0.01).
§ The Y x M x A x D x T interaction is assumed to be zero and its mean square treated as the within cell error mean square.

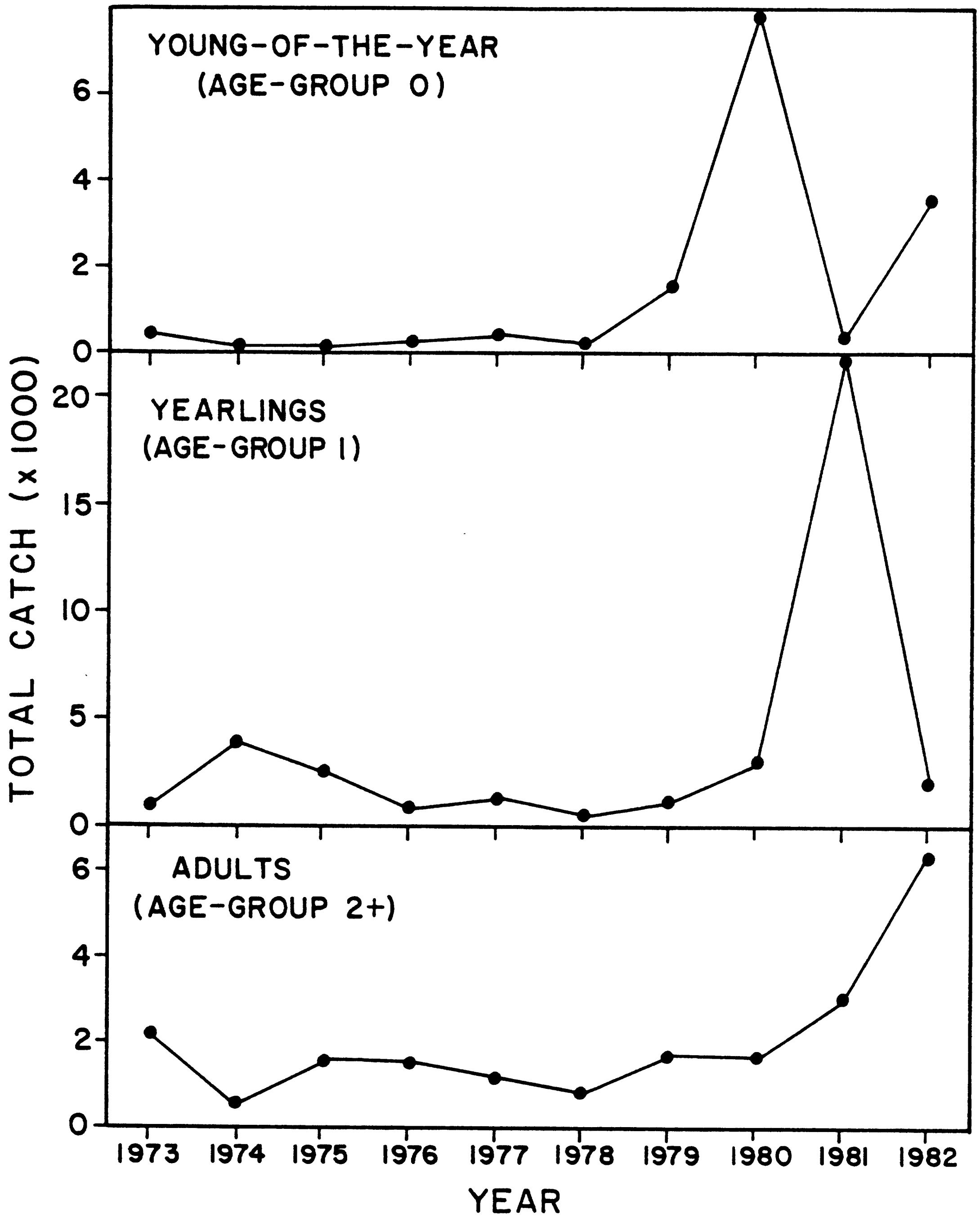


Fig. 13. Yearly total catch of three age-groups of yellow perch. Fish were caught from April to October by standard series netting in Cook Plant study areas, southeastern Lake Michigan.

class was produced. This recent population increase may be related to the decline in the alewife population.

The Lake Michigan yellow perch population declined in the 1960s as the alewife population increased (Smith 1970, Wells 1977). Alewife predation on yellow perch larvae has been suggested as the mechanism for this interrelationship (Wells 1977). The recent yellow perch increase in the study areas indicates that alewife interfered with yellow perch production. However, while adult alewives have been at a low abundance since 1977 (Fig. 3), yellow perch did not produce a strong year class until 3 yr later in 1980. This was also the first year that young-of-the-year alewives declined substantially. Because alewife larvae generally hatch after yellow perch and most yearling alewives remain offshore, only adult alewives are potential predators of yellow perch larvae. Therefore, the interrelationship of alewife and yellow perch may be more complex than just predation by adult alewives on larval yellow perch.

## COMMON SPECIES

### Brown Trout

Yearly brown trout catches averaged 60 fish per year from 1973 to 1982 (Appendix 4). The largest catch of 162 fish occurred in 1978, and the smallest of only 3 fish in 1981. Sixty percent of all brown trout were seined while 39% were gillnetted. Fifty-two percent of all fish were caught during the day.

Thirty-one percent of all brown trout collected were juveniles <254 mm in length. Annual catch of these juveniles was positively correlated (Spearman's rank correlation coefficient of 0.97; $P<0.05$) with annual number of juvenile

brown trout stocked at the two closest planting sites - the St. Joseph and Galien rivers. Evidently, planted brown trout migrate alongshore before moving to deeper water in Lake Michigan.

Analyses of 1973-1979 seine and gill net data revealed a tendency during operational years for more brown trout to be present in the Cook area than at Warren Dunes (Tesar et al. 1985). This difference was assumed to be caused by an attraction to the plant area because of the plant's discharges. Brown trout may also have been attracted to forage fish and crayfish on the riprap. Addition of 1980-1982 seine data showed no major differences in operational years' catches at the three seining stations (Fig. 14). Gill net catches were again larger in the Cook area in 1981 and 1982. However, statistical analyses revealed no significant differences in either seine or gill net catches between the two study areas in operational years; preoperational and operational years' catches were also similar (Table 31). Consequently, the 10 yr of catch data have demonstrated no significant variation attributable to plant operation.

Like other salmonids in the study areas, brown trout were primarily eating fish. Alewives and rainbow smelt constituted, respectively, 79% and 13% by weight of the fish eaten by 150 brown trout. Slimy sculpins, spottail shiners, bloaters, gizzard shad, and johnny darters were also eaten. Invertebrates, especially terrestrial insects, comprised 50% of the food eaten by 70 juvenile brown trout <20 cm in length; fish comprised the other 50%. Brown trout juveniles, like chinook salmon, coho salmon, and rainbow trout juveniles, apparently feed at the surface when inshore in Lake Michigan.

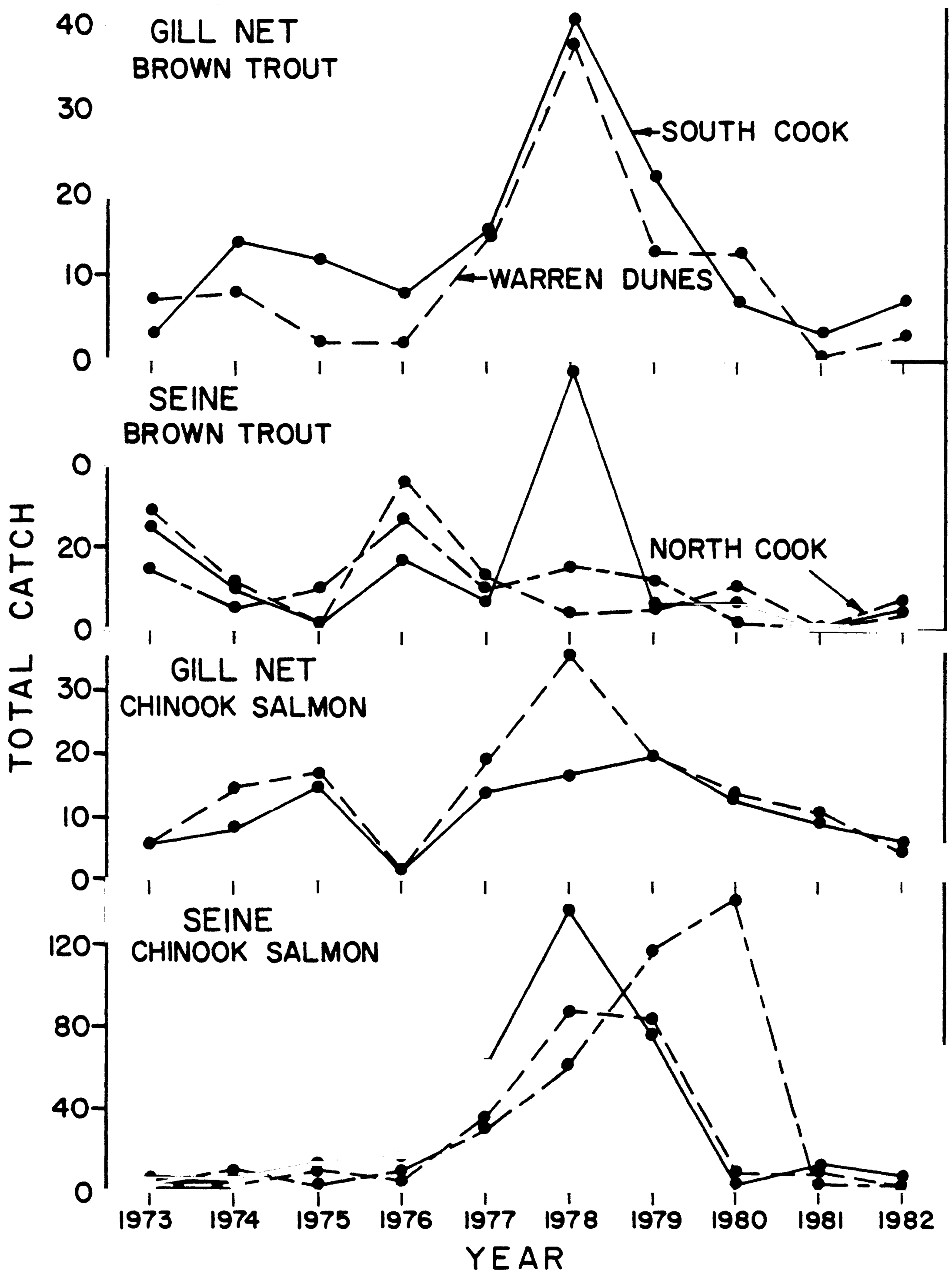


Fig. 14. Annual catches of brown trout and chinook salmon in the study areas of southeastern Lake Michigan. The Cook Plant began operation in 1975.

Table 31. Results of the Kruskal-Wallis test applied to April, May, and June, 1973-1982 brown trout catch data from Cook Plant study areas, southeastern Lake Michigan. Sta = stations(s), A = 1 m north Cook, B = 1 m south Cook, F = 1 m Warren Dunes, C = 6 m south Cook, D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes.

| Source of variation | H Statistic | Significance |
|---|---|---|
| | ***Gill net*** | |
| Sta C (1973-74) vs. Sta G (1973-74) | 0.21333 | 0.6442 |
| Sta D (1973-74) vs. Sta H (1973-74) | 0.12000 | 0.7290 |
| Sta C,D (1973-74) vs. Sta G,H (1973-74) | 0.02721 | 0.8690 |
| Sta C (1973-74) vs. Sta C (1975-82) | 0.85383 | 0.3555 |
| Sta D (1973-74) vs. Sta D (1975-82) | 0.32821 | 0.5667 |
| Sta G (1973-74) vs. Sta G (1975-82) | 0.23087 | 0.6309 |
| Sta H (1973-74) vs. Sta H (1975-82) | 0.44262 | 0.5059 |
| Sta C,D (1973-74) vs. Sta C,D (1975-82) | 1.20770 | 0.2718 |
| Sta G,H (1973-74) vs. Sta G,H (1975-82) | 0.00430 | 0.9477 |
| Sta C (1975-82) vs. Sta G (1975-82) | 1.92820 | 0.1650 |
| Sta D (1975-82) vs. Sta H (1975-82) | 0.32668 | 0.5676 |
| Sta C,D (1975-82) vs. Sta G,H (1975-82) | 1.98920 | 0.1584 |
| | ***Seine*** | |
| Sta A (1973-74) vs. Sta F (1973-74) | 0.12000 | 0.7290 |
| Sta B (1973-74) vs. Sta F (1973-74) | 0.24083 | 0.6236 |
| Sta A,B (1973-74) vs. Sta F (1973-74) | 0.23677 | 0.6266 |
| Sta A (1973-74) vs. Sta A (1975-82) | 0.94134 | 0.3319 |
| Sta B (1973-74) vs. Sta B (1975-82) | 1.33410 | 0.2481 |
| Sta F (1973-74) vs. Sta F (1975-82) | 2.32450 | 0.1273 |
| Sta A,B (1973-74) vs. Sta A,B (1975-82) | 2.30680 | 0.1288 |
| Sta A (1975-82) vs. Sta F (1975-82) | 0.11362 | 0.7361 |
| Sta B (1975-82) vs. Sta F (1975-82) | 0.00344 | 0.9533 |
| Sta A,B (1975-82) vs. Sta F (1975-82) | 0.02593 | 0.8721 |

## Chinook Salmon

Annual chinook salmon catches varied considerably over the 10-yr period, from a high of 337 fish in 1978 to a low of 25 fish in 1982. Over the 10 yr, catches averaged 124 fish per year. The 1980 catch of 182 fish was above average, while in 1981 and 1982 the catches of 46 and 25 fish, respectively, were small. Gill nets caught 21% of the fish, while seines contributed 78%.

Most chinook salmon were collected in spring and fall when lake temperatures were low and fish move shoreward and alongshore. Occasional summer catches also occurred when temperatures were low. Chinook salmon in Lake Michigan are maintained by plantings, although some natural reproduction occurs (Carl 1982). No correlation existed between number of juveniles collected annually in the study areas and number of chinook salmon stocked at the closest planting site - the St. Joseph River.

Analysis of 1973-1979 catch data showed no variation in chinook salmon abundance or distribution related to plant operation (Tesar et al. 1985). Catches in the two study areas were similar during all operational years (Fig. 14). Statistical analyses showed no significant differences in catch between the study areas; catches in the Cook area between preoperational and operational years were also similar (Table 32). Consequently, the 10 yr of catch data have demonstrated no plant effects on chinook salmon.

Alewives and rainbow smelt comprised, respectively, 88% and 12% by weight of fish eaten by 45 chinook salmon. Invertebrates, especially terrestrial insects, comprised 69% of the food eaten by 67 chinook salmon <20 cm in length; the remainder of the food was fish, mostly alewives.

Table 32. Results of the Kruskal-Wallis test applied to April, May, June, and July, 1973-1982 chinook salmon catch data from Cook Plant study areas, southeastern Lake Michigan. Sta = stations(s), A = 1 m north Cook, B = 1 m south Cook, F = 1 m Warren Dunes, C = 6 m south Cook D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes.

| Source of variation | H Statistic | Significance |
|---|---|---|
| *Gill net (night only)* | | |
| Sta C (1973-74) vs. Sta G (1973-74) | 1.58820 | 0.2076 |
| Sta D (1973-74) vs. Sta H (1973-74) | 0.01103 | 0.9164 |
| Sta C,D (1973-74) vs. Sta G,H (1973-74) | 0.65661 | 0.4178 |
| Sta C (1973-74) vs. Sta C (1975-82) | 1.17070 | 0.2793 |
| Sta D (1973-74) vs. Sta D (1975-82) | 0.41273 | 0.5206 |
| Sta G (1973-74) vs. Sta G (1975-82) | 0.01143 | 0.9730 |
| Sta H (1973-74) vs. Sta H (1975-82) | 0.05602 | 0.8129 |
| Sta C,D (1973-74) vs. Sta C,D (1975-82) | 1.56480 | 0.2110 |
| Sta G,H (1973-74) vs. Sta G,H (1975-82) | 0.03042 | 0.8615 |
| Sta C (1975-82) vs. Sta G (1975-82) | 0.28846 | 0.5912 |
| Sta D (1975-82) vs. Sta H (1975-82) | 0.73846 | 0.3902 |
| Sta C,D (1975-82) vs. Sta G,H (1975-82) | 0.03911 | 0.8432 |
| *Seine* | | |
| Sta A (1973-74) vs. Sta F (1973-74) | 1.15380 | 0.2828 |
| Sta B (1973-74) vs. Sta F (1973-74) | 0.65661 | 0.4178 |
| Sta A,B (1973-74) vs. Sta F (1973-74) | 1.19580 | 0.2742 |
| Sta A (1973-74) vs. Sta A (1975-82) | 0.07990 | 0.7774 |
| Sta B (1973-74) vs. Sta B (1975-82) | 0.19274 | 0.6606 |
| Sta F (1973-74) vs. Sta F (1975-82) | 1.14600 | 0.2844 |
| Sta A,B (1973-74) vs. Sta A,B (1975-82) | 0.26642 | 0.6057 |
| Sta A (1975-82) vs. Sta F (1975-82) | 0.22035 | 0.6388 |
| Sta B (1975-82) vs. Sta F (1975-82) | 0.16216 | 0.6872 |
| Sta A,B (1975-82) vs. Sta F (1975-82) | 0.25418 | 0.6141 |

Coho Salmon

From 1973 to 1982, 423 coho salmon were collected in the study areas. Annual catches varied substantially, from 147 fish in 1974 to only 3 fish in 1982. Catches in 1980 and 1981 were also small. Seventy-three percent of the coho salmon were gillnetted while 27% were seined.

Most coho salmon were seined in the spring. Occasional summer catches occurred when cooler water was inshore. Large spring catches were the result of the fish being inshore, presumably following prey species, and the result of spring planting of juveniles. Seine catches varied with the number of fish stocked at the nearest planting site - the St. Joseph River. In 1973, 1975, 1976, 1980, 1981, and 1982, coho salmon were not stocked in the river, and seine catches of juveniles <254 mm in length averaged less than 1 fish per year. During the other 4 study yr, plantings ranged from 139,000 to 200,000 fish, and seine catches averaged 25 fish per year.

Examination of 1973-1979 catch data showed no variation in coho salmon abundance or distribution attributable to plant operation (Tesar et al. 1985). Catch data for 1980-1982 showed similar catches in the study areas (Fig. 15). Statistical analyses of all 10 yr of data revealed no significant differences in area catches in operational years (Table 33). The significantly larger seine catch in preoperational years at Cook was presumed to be the result of irregular annual plantings of juveniles. Consequently, the 10 yr of catch data showed no effect of plant operation on coho salmon distribution or abundance. Annual coho salmon catches varied as a result of stocking quantities and temperature. The species prefers cool water and remains offshore when temperature is high in the study areas.

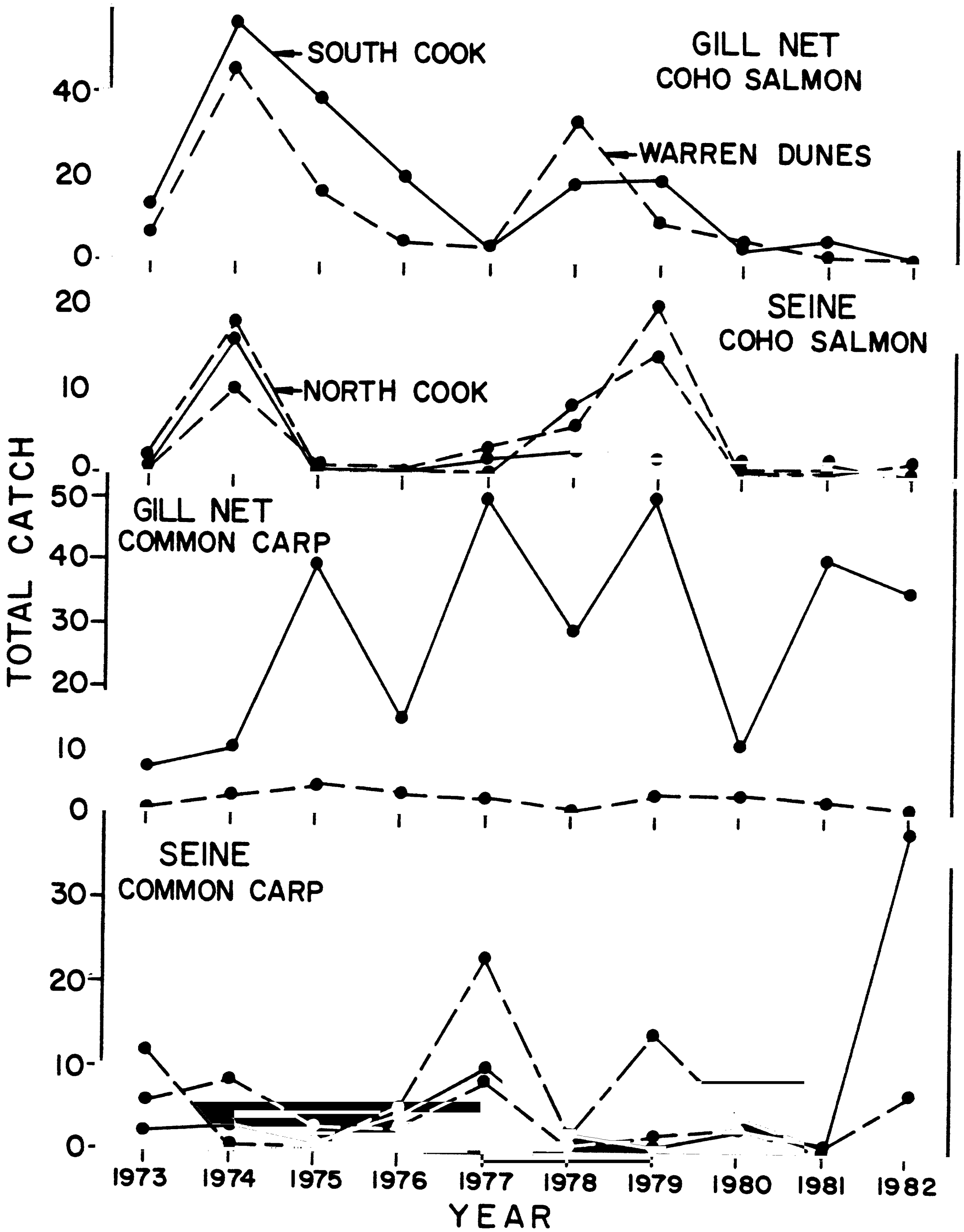


Fig. 15. Annual catches of coho salmon and common carp in the study areas of southeastern Lake Michigan. The Cook Plant began operation in 1975.

Table 33. Results of the Kruskal-Wallis test applied to April and May, 1973-1982 coho salmon catch data from Cook Plant study areas, southeastern Lake Michigan. Sta = stations(s), A = 1 m north Cook, B = 1 m south Cook, F = 1 m Warren Dunes, C = 6 m south Cook, D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes.

| Source of variation | H Statistic | Significance |
|---|---|---|
| *Gill net (night only)* | | |
| Sta C (1973-74) vs. Sta G (1973-74) | 0.33333 | 0.5637 |
| Sta D (1973-74) vs. Sta H (1973-74) | 0.33333 | 0.5637 |
| Sta C,D (1973-74) vs. Sta G,H (1973-74) | 0.62040 | 0.4309 |
| Sta C (1973-74) vs. Sta C (1975-82) | 1.28570 | 0.2568 |
| Sta D (1973-74) vs. Sta D (1975-82) | 0.32143 | 0.5708 |
| Sta G (1973-74) vs. Sta G (1975-82) | 0.89286 | 0.3447 |
| Sta H (1973-74) vs. Sta H (1975-82) | 0.03571 | 0.8501 |
| Sta C,D (1973-74) vs. Sta C,D (1975-82) | 1.60780 | 0.2048 |
| Sta G,H (1973-74) vs. Sta G,H (1975-82) | 0.89634 | 0.3438 |
| Sta C (1975-82) vs. Sta G (1975-82) | 0.00888 | 0.9249 |
| Sta D (1975-82) vs. Sta H (1975-82) | 0.46023 | 0.4975 |
| Sta C,D (1975-82) vs. Sta G,H (1975-82) | 0.14644 | 0.7020 |
| *Seine* | | |
| Sta A (1973-74) vs. Sta F (1973-74) | 0.46599 | 0.4948 |
| Sta B (1973-74) vs. Sta F (1973-74) | 0.27574 | 0.5995 |
| Sta A,B (1973-74) vs. Sta F (1973-74) | 0.49594 | 0.4813 |
| Sta A (1973-74) vs. Sta A (1975-82) | 2.06510 | 0.1507 |
| Sta B (1973-74) vs. Sta B (1975-82) | 2.21340 | 0.1368 |
| Sta F (1973-74) vs. Sta F (1975-82) | 0.43474 | 0.5097 |
| Sta A,B (1973-74) vs. Sta A,B (1975-82) | 4.30500 | 0.0380* |
| Sta A (1975-82) vs. Sta F (1975-82) | 0.00288 | 0.9572 |
| Sta B (1975-82) vs. Sta F (1975-82) | 0.02596 | 0.8720 |
| Sta A,B (1975-82) vs. Sta F (1975-82) | 0.01546 | 0.9010 |

*Significant ($P < 0.05$).

Alewives and rainbow smelt comprised, respectively, 90% and 9% by weight of the fish eaten by 153 coho salmon. Slimy sculpins, spottail shiners, and yellow perch were also eaten. Invertebrates, especially terrestrial insects, constituted 60% of the food eaten by 35 coho salmon <20 cm in length; the remaining food was fish.

Common Carp

Almost 500 common carp were collected from 1973 to 1982. Annual catches varied from 92 fish in 1977 to 27 fish in 1973 and 1974. The 1980 catch was small, while the 1982 catch of 84 fish was the second largest. In 1981, the catch was close to the 10-yr average of 49 fish. Sixty-two percent of all fish were gillnetted and 34% were seined.

Analysis of 1973-1979 catch data revealed that plant operation, specifically the discharge plumes, attracted common carp to the plant area (Tesar et al. 1985). Gill net catches in the Cook area were significantly larger in operational years than in preoperational years. Also, catches were significantly larger in the Cook area compared to the Warren Dunes area only in operational years. Gill net catches from 1980 to 1982 continued to be larger in the Cook area (Fig. 15). Statistical tests of all 10 yr of data agreed with the 1973-1979 data analysis: significantly larger catches at Cook in all operational years, consequently reaffirming that plant operation affected common carp (Table 34).

Seine data did not show significantly larger catches at Cook stations (Table 34). However, during 5 of the 8 operational yr the seine catch was smallest at Warren Dunes (Fig. 15).

Table 34. Results of the Kruskal-Wallis test applied to May, July, and August through October, 1973-1982 common carp catch data from Cook Plant study areas, southeastern Lake Michigan. Sta = stations(s), A = 1 m north Cook, B = 1 m south Cook, F = 1 m Warren Dunes, C = 6 m south Cook D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes.

| Source of variation | H Statistic | Significance |
|---|---|---|
| *Gill net* | | |
| Sta C (1973-74) vs. Sta G (1973-74) | 0.70317 | 0.4017 |
| Sta D (1973-74) vs. Sta H (1973-74) | 0.61537 | 0.4328 |
| Sta C,D (1973-74) vs. Sta G,H (1973-74) | 1.33330 | 0.2482 |
| Sta C (1973-74) vs. Sta C (1975-82) | 6.79500 | 0.0091* |
| Sta D (1973-74) vs. Sta D (1975-82) | 1.30370 | 0.2535 |
| Sta G (1973-74) vs. Sta G (1975-82) | 0.18937 | 0.6634 |
| Sta H (1973-74) vs. Sta H (1975-82) | 0.02146 | 0.8835 |
| Sta C,D (1973-74) vs. Sta C,D (1975-82) | 7.16650 | 0.0074* |
| Sta G,H (1973-74) vs. Sta G,H (1975-82) | 0.16625 | 0.6835 |
| Sta C (1975-82) vs. Sta G (1975-82) | 28.07000 | 0.0000* |
| Sta D (1975-82) vs. Sta H (1975-82) | 9.43320 | 0.0021* |
| Sta C,D (1975-82) vs. Sta G,H (1975-82) | 35.05400 | 0.0000* |
| *Seine (night only)* | | |
| Sta A (1973-74) vs. Sta F (1973-74) | 0.00571 | 0.9397 |
| Sta B (1973-74) vs. Sta F (1973-74) | 0.00000 | 0.9999 |
| Sta A,B (1973-74) vs. Sta F (1973-74) | 0.00194 | 0.9649 |
| Sta A (1973-74) vs. Sta A (1975-82) | 0.09191 | 0.7618 |
| Sta B (1973-74) vs. Sta B (1975-82) | 0.04765 | 0.8272 |
| Sta F (1973-74) vs. Sta F (1975-82) | 0.05882 | 0.8084 |
| Sta A,B (1973-74) vs. Sta A,B (1975-82) | 0.13730 | 0.7110 |
| Sta A (1975-82) vs. Sta F (1975-82) | 0.06502 | 0.7987 |
| Sta B (1975-82) vs. Sta F (1975-82) | 0.00058 | 0.9808 |
| Sta A,B (1975-82) vs. Sta F (1975-82) | 0.01785 | 0.8937 |

*Significant ($P < 0.05$).

A consequence of common carp being attracted to the plant area has been spawning. Larvae were collected at the plant site only in operational years.

Gizzard Shad

Over 1,200 gizzard shad were collected during the 10 study yr. Annual catches ranged from 389 fish in 1982 to 23 fish in 1973. A large seine catch of young-of-the-year in November caused the 1982 catch to be very large. Catches in 1980 and 1981 were smaller than average. Fifty-one percent of all gizzard shad were gillnetted, while 46% were seined. Most gizzard shad were collected during late summer and fall.

Analysis of 1973-1979 gill net data showed significantly larger catches in the Cook area during operational years (Tesar et al. 1985). This plant effect was assumed to be an attraction of fish to the plant's discharges. From 1980 to 1982, gill net catches were again larger at Cook (Fig. 16). Statistical tests of 1973-1982 gill net data also showed a significantly larger catch in operational years than in preoperational years in the Cook area and a significantly larger catch at Cook than at Warren Dunes in operational years (Table 35). Thus, the plant effect was confirmed by all 10 yr of gill net catch data.

Seine data did not show any trend among station catches in operational years (Fig. 16). Distribution of gizzard shad in the 1-m seining depths may be too variable to detect a plant effect, or the plume may not influence the distribution of this species at 1 m.

Johnny Darter

Almost 2,500 johnny darters were collected during the 10 study yr. Annual catches varied more than 4 fold from a high of 423 fish in 1977 to a low of 92 fish in 1982. Catches in 1980 and 1981 were smaller than the 10-yr

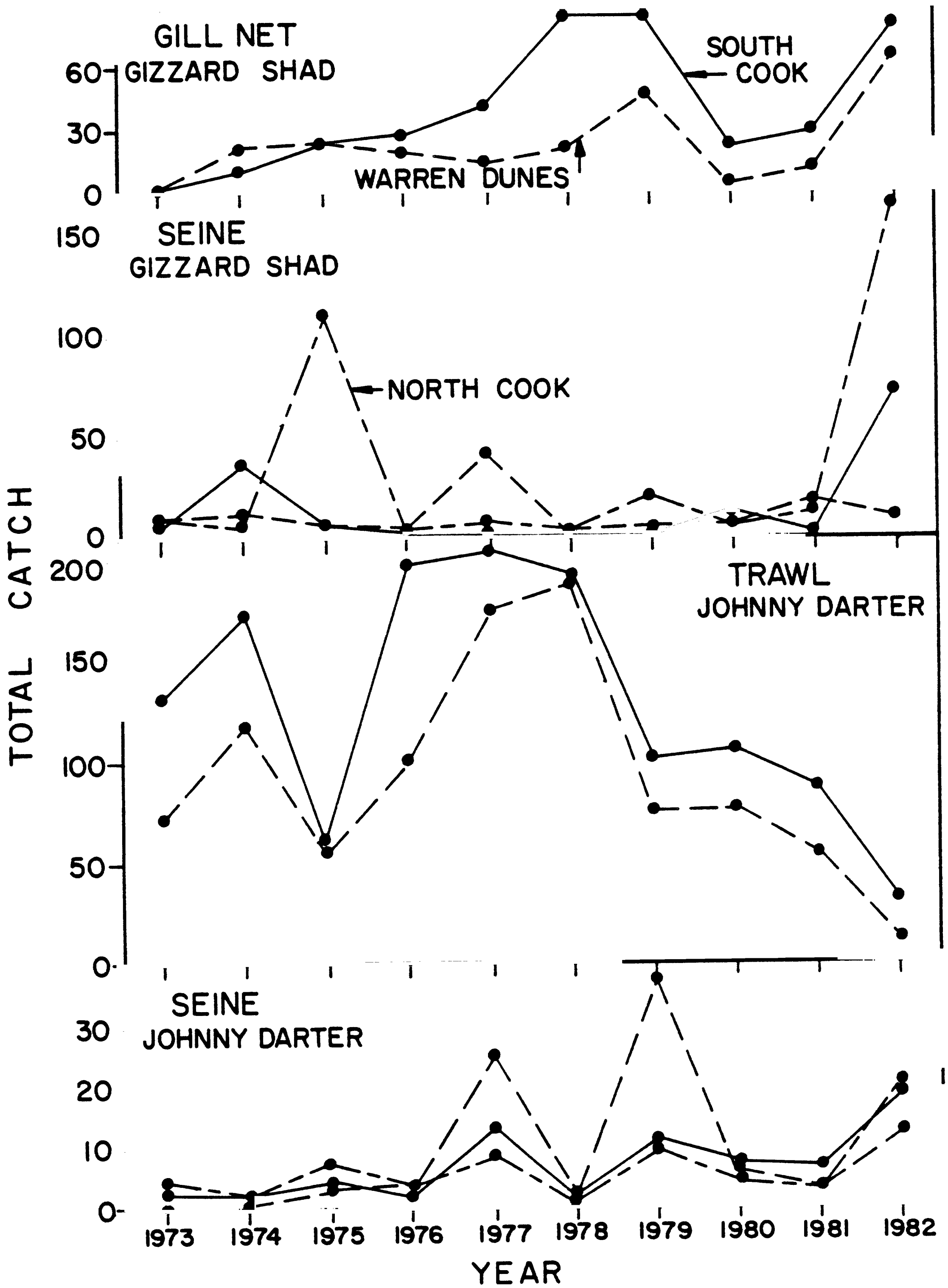


Fig. 16. Annual catches of gizzard shad and johnny darters in the study areas of southeastern Lake Michigan. The Cook Plant began operation in 1975.

Table 35. Results of the Kruskal-Wallis test applied to September through November, 1973-1982 gizzard shad catch data from Cook Plant study areas, southeastern Lake Michigan. Sta = stations(s), A = 1 m north Cook, B = 1 m south Cook, F = 1 m Warren Dunes, C = 6 m south Cook D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes.

| Source of variation | H Statistic | Significance |
|---|---|---|
| | *Gill net (night only)* | |
| Sta C (1973-74) vs. Sta G (1973-74) | 0.00641 | 0.9362 |
| Sta D (1973-74) vs. Sta H (1973-74) | 0.16026 | 0.6889 |
| Sta C,D (1973-74) vs. Sta G,H (1973-74) | 0.12000 | 0.7290 |
| Sta C (1973-74) vs. Sta C (1975-82) | 2.92740 | 0.0871 |
| Sta D (1973-74) vs. Sta D (1975-82) | 2.03290 | 0.1539 |
| Sta G (1973-74) vs. Sta G (1975-82) | 0.11358 | 0.7361 |
| Sta H (1973-74) vs. Sta H (1975-82) | 0.00000 | 0.9999 |
| Sta C,D (1973-74) vs. Sta C,D (1975-82) | 4.91800 | 0.0266* |
| Sta G,H (1973-74) vs. Sta G,H (1975-82) | 0.07684 | 0.7816 |
| Sta C (1975-82) vs. Sta G (1975-82) | 2.58670 | 0.1078 |
| Sta D (1975-82) vs. Sta H (1975-82) | 1.58210 | 0.2085 |
| Sta C,D (1975-82) vs. Sta G,H (1975-82) | 4.62530 | 0.0315* |
| | *Seine* | |
| Sta A (1973-74) vs. Sta F (1973-74) | 0.10083 | 0.7508 |
| Sta B (1973-74) vs. Sta F (1973-74) | 0.12000 | 0.7290 |
| Sta A,B (1973-74) vs. Sta F (1973-74) | 0.00028 | 0.9866 |
| Sta A (1973-74) vs. Sta A (1975-82) | 0.21346 | 0.6441 |
| Sta B (1973-74) vs. Sta B (1975-82) | 0.24898 | 0.6178 |
| Sta F (1973-74) vs. Sta F (1975-82) | 0.18861 | 0.6641 |
| Sta A,B (1973-74) vs. Sta A,B (1975-82) | 0.45665 | 0.4992 |
| Sta A (1975-82) vs. Sta F (1975-82) | 0.49485 | 0.4818 |
| Sta B (1975-82) vs. Sta F (1975-82) | 0.30607 | 0.5801 |
| Sta A,B (1975-82) vs. Sta F (1975-82) | 0.00755 | 0.9308 |

*Significant ($P < 0.05$).

average catch of 243 fish. Abundance has been steadily decreasing since 1977. Ninety-one percent of the fish were caught in trawls, and 9% in seines. This species was never gillnetted.

Johnny darters were present in all months sampled by trawling. Abundance was greatest during spring and early summer, when the species moves shoreward to spawn. Johnny darters also became residents and spawned on the plant's riprap (Dorr and Jude 1980). This species moved shoreward at night, which was reflected in 75% of the fish being caught at night.

Analysis of 1973-1979 trawl data showed a significantly larger catch at the 6-m Cook station than at the 6-m Warren Dunes station (Tesar et al. 1985). Attraction to the plant's riprap was assumed to be the cause. Trawl catches during all years, including 1980-1982, were larger in the Cook area (Fig. 16). Statistical tests of 1973-1982 trawl data showed a significantly larger catch at the Cook 6-m station only in operational years (Table 36). These results and diver observations (Dorr and Jude 1980) again suggest an attraction to the plant's riprap. The significantly smaller catch at Warren Dunes in operational years compared with preoperational years may have resulted from the abundance decline during the last 4 yr.

The 10 yr of seine data demonstrated no plant effects on johnny darters. No trends occurred in station catches during operational years (Fig. 16).

Lake Trout

Almost 1,500 lake trout were collected over the 10 yr. Annual catches varied considerably, from a high of 286 fish in 1978 to 37 fish in 1976. Catches in 1980, 1981, and 1982 were near the 10-yr average of 145 fish per year. Gill nets collected 94% of all the lake trout caught.

Table 36. Results of the Kruskal-Wallis test applied to April through October, 1973-1982 johnny darter trawl catch data from Cook Plant study areas, southeastern Lake Michigan. Sta = stations(s), C = 6 m south Cook D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes.

| Source of variation | H Statistic | Significance |
|---|---|---|
| Sta C (1973-74) vs. Sta G (1973-74) | 1.59210 | 0.2070 |
| Sta D (1973-74) vs. Sta H (1973-74) | 0.06451 | 0.7995 |
| Sta C,D (1973-74) vs. Sta G,H (1973-74) | 0.55049 | 0.4581 |
| Sta C (1973-74) vs. Sta C (1975-82) | 1.02140 | 0.3122 |
| Sta D (1973-74) vs. Sta D (1975-82) | 3.00940 | 0.0828 |
| Sta G (1973-74) vs. Sta G (1975-82) | 2.41810 | 0.1199 |
| Sta H (1973-74) vs. Sta H (1975-82) | 1.36780 | 0.2422 |
| Sta C,D (1973-74) vs. Sta C,D (1975-82) | 3.42480 | 0.0642 |
| Sta G,H (1973-74) vs. Sta G,H (1975-82) | 4.09690 | 0.0430* |
| Sta C (1975-82) vs. Sta G (1975-82) | 12.64400 | 0.0004* |
| Sta D (1975-82) vs. Sta H (1975-82) | 1.21010 | 0.2713 |
| Sta C,D (1975-82) vs. Sta G,H (1975-82) | 2.80300 | 0.0941 |

*Significant ($P < 0.05$).

Lake trout were most abundant in fall and spring. Catches during summer occurred when inshore temperatures were low. Fall and spring abundances resulted from inshore movements for spawning in fall and possibly for feeding in spring when prey species move shoreward. Lake trout also move shoreward at night, resulting in 87% of the fish being caught at night.

Analysis of 1973-1979 gill net data revealed no significant differences in catches of lake trout in the two study areas (Tesar et al. 1985). However, there was a tendency for greater catches in the Cook area during these study years, presumably because lake trout are attracted to the plant's riprap for spawning. Gill net catches in 1980 and 1982 also were larger at Cook (Fig. 17). Statistical tests showed that only in pre-operational years was this difference significant (Table 37). No evidence of natural reproduction was found, but eggs washed ashore in November 1975 may have been laid on the riprap (Jude et al. 1979).

Lake trout in Lake Michigan are maintained by plantings. However, in contrast to other salmonids, very few juvenile fish were collected in the study areas. Apparently juveniles move offshore rather than alongshore, as other planted salmonids do, after being planted. Ninety-eight percent of all lake trout collected had clipped fins.

Lake trout >30 cm in length ate almost 100% fish over all seasons; alewife and rainbow smelt constituted, respectively, 88% and 9% by weight of the prey. Spottail shiners, slimy sculpins, gizzard shad, yellow perch, and trout-perch also were eaten. Lake trout <30 cm also ate mainly alewives, but 6% of the diet in spring and summer was invertebrates.

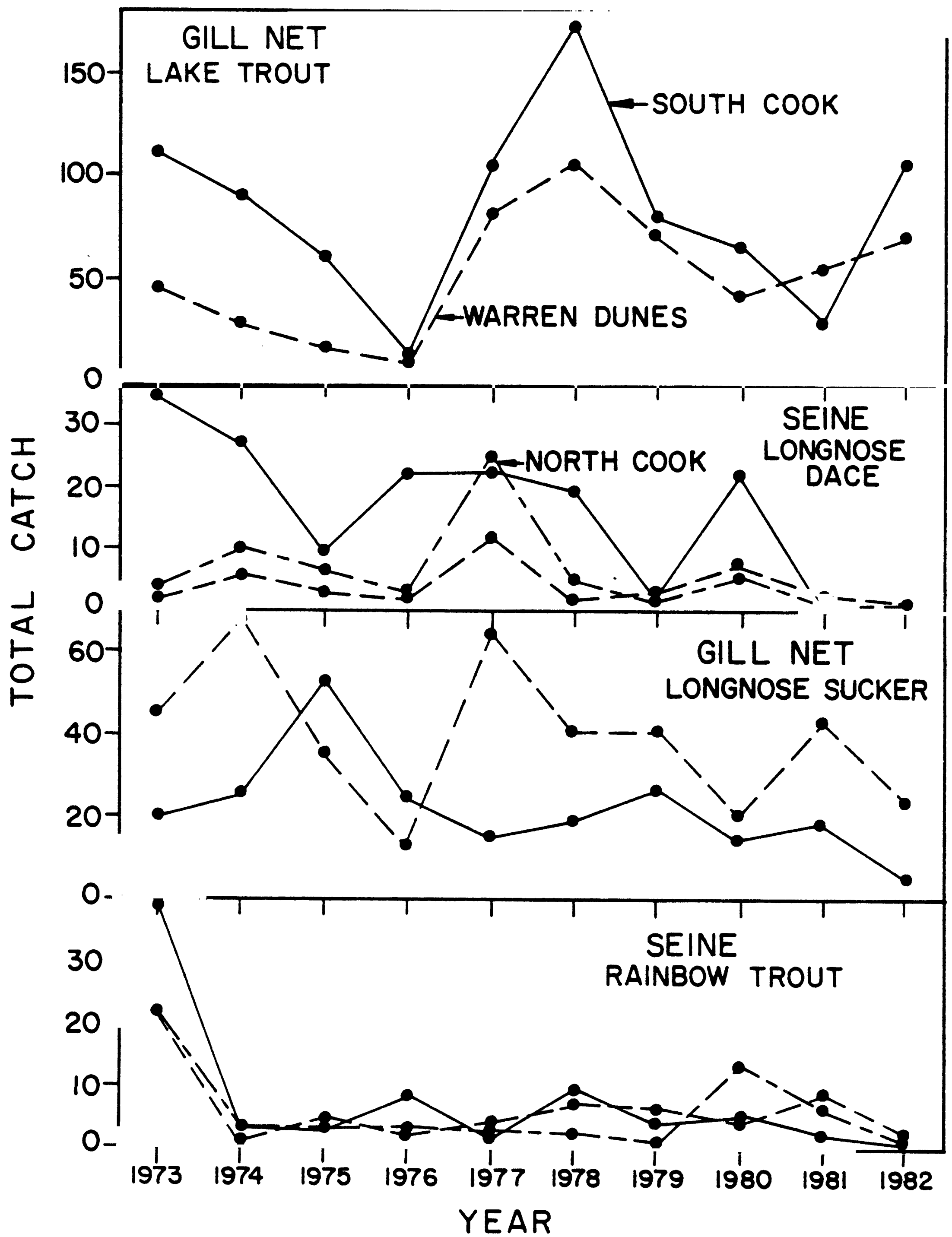


Fig. 17. Annual catches of lake trout, longnose dace, longnose suckers, and rainbow trout in the study areas of southeastern Lake Michigan. The Cook Plant began operation in 1975.

Table 37. Results of the Kruskal-Wallis test applied to May, June, October, and November, 1973-1982 lake trout gillnet catch data from Cook Plant study areas, southeastern Lake Michigan. Sta = stations(s), C = 6 m south Cook, D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes.

| Source of variation | H Statistic | Significance |
|---|---|---|
| Sta C (1973-74) vs. Sta G (1973-74) | 2.38780 | 0.1223 |
| Sta D (1973-74) vs. Sta H (1973-74) | 2.27270 | 0.1317 |
| Sta C,D (1973-74) vs. Sta G,H (1973-74) | 4.52930 | 0.0333* |
| Sta C (1973-74) vs. Sta C (1975-82) | 0.73962 | 0.3898 |
| Sta D (1973-74) vs. Sta D (1975-82) | 0.04952 | 0.8239 |
| Sta G (1973-74) vs. Sta G (1975-82) | 0.18233 | 0.6694 |
| Sta H (1973-74) vs. Sta H (1975-82) | 2.63670 | 0.1044 |
| Sta C,D (1973-74) vs. Sta C,D (1975-82) | 0.19682 | 0.6573 |
| Sta G,H (1973-74) vs. Sta G,H (1975-82) | 2.01780 | 0.1555 |
| Sta C (1975-82) vs. Sta G (1975-82) | 0.87246 | 0.3503 |
| Sta D (1975-82) vs. Sta H (1975-82) | 1.48840 | 0.2225 |
| Sta C,D (1975-82) vs. Sta G,H (1975-82) | 2.30330 | 0.1291 |

*Significant ($P < 0.05$).

Longnose Dace

Only 260 longnose dace were collected over the 10 yr. Annual catches varied substantially, from 60 fish in 1977 to 2 fish in 1982. Only 3 fish were caught in 1981, while 34 fish were caught in 1980. All but 1 fish were seined.

Most longnose dace were caught in the fall, although they were present in most sampling months. A shoreward movement by young-of-the-year contributed to the fall abundance. An inshore movement at night resulted in 82% of the fish being seined at night.

Examination of 1973-1982 catch data showed no effects of plant operation on longnose dace numbers (Tesar et al. 1985). There was a tendency toward larger catches at the south Cook station during all study years (Fig. 17). Near this station there is some gravel and plant construction rubble which may have attracted this species. Longnose dace prefer gravel-rock substrates to sandy areas (Brazo et al. 1978). Three of the last 4 yr of the study have shown fewer differences in catch between the three stations. Apparently the shifting beach sand is covering up the gravel and rubble near the south Cook station, thereby diminishing the attraction.

Longnose Sucker

Almost 750 longnose suckers were collected. Annual catches were relatively stable, varying from 99 fish in 1977 to 40 fish in 1976. Catches in 1980, 1981, and 1982 were all smaller than the 10-yr average of 74 fish. Gill nets caught 83% of the fish, and seines contributed 14%.

Longnose suckers were year-round residents in the study areas. During most years, there was a slight abundance increase in late spring and early

summer. This species moves shoreward at night, which contributed to 82% of the fish being caught at night.

Examination of 1973 to 1979 gill net data showed larger catches in the Warren Dunes area during most study years (Tesar et al. 1985). We attributed this difference to an avoidance of the Cook area because of construction and discharges rather than an attraction to Warren Dunes. Studies at other Lake Michigan power plants (WEPC and WMPC 1975, Brazo and Liston 1979, Jude et al. 1981) also indicated an avoidance of plant sites by longnose suckers and white suckers. Gill net catches in 1980-1982 also showed a greater abundance at Warren Dunes (Fig. 17). Statistical tests demonstrated that only in operational years was this difference significant (Table 38).

Rainbow Trout

Just over 200 rainbow trout were collected over the 10 yr. This species was the least abundant of the five salmonid species found in the study areas. Annual catches varied from 86 fish in 1973 to 4 fish in 1982. Catches in 1980 and 1981 were near the 10-yr average of 21 fish per year. Ninety-one percent of all fish were seined, while 9% were gillnetted.

Rainbow trout were generally caught throughout the year, but they tended to avoid inshore waters during warm summer months. However, some juveniles were seined in 25°C water. Seventy-six percent of the total catch were juveniles <254 mm in length. These, presumably planted fish, tended to remain at 1-m seining depths from spring to summer. Unlike brown trout, no correlation existed between numbers of juvenile rainbow trout collected and the numbers planted in the nearest stocking locations - the St. Joseph and Galien rivers. Because the Michigan Department of Natural Resources plants varying numbers of

Table 38. Results of the Kruskal-Wallis test applied to April through October, 1973-1982 longnose sucker night gillnet catch data from Cook Plant study areas, southeastern Lake Michigan. Sta = stations(s), C = 6 m south Cook, D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes.

| Source of variation | H Statistic | Significance |
|---|---|---|
| Sta C (1973-74) vs. Sta G (1973-74) | 0.44388 | 0.5053 |
| Sta D (1973-74) vs. Sta H (1973-74) | 1.31950 | 0.2507 |
| Sta C,D (1973-74) vs. Sta G,H (1973-74) | 1.76180 | 0.1844 |
| Sta C (1973-74) vs. Sta C (1975-82) | 1.88460 | 0.1698 |
| Sta D (1973-74) vs. Sta D (1975-82) | 0.14573 | 0.7026 |
| Sta G (1973-74) vs. Sta G (1975-82) | 2.17740 | 0.1401 |
| Sta H (1973-74) vs. Sta H (1975-82) | 0.00022 | 0.9883 |
| Sta C,D (1973-74) vs. Sta C,D (1975-82) | 0.48367 | 0.4868 |
| Sta G,H (1973-74) vs. Sta G,H (1975-82) | 1.15170 | 0.2832 |
| Sta C (1975-82) vs. Sta G (1975-82) | 2.10800 | 0.1465 |
| Sta D (1975-82) vs. Sta H (1975-82) | 3.01730 | 0.0824 |
| Sta C,D (1975-82) vs. Sta G,H (1975-82) | 5.11650 | 0.0237* |

*Significant ($P < 0.05$).

young-of-the-year in the fall and varying numbers of yearlings in the spring, catches in the study areas could also vary considerably.

Examination of 1973-1979 seine data showed no variation attributable to plant effects (Tesar et al. 1985). Catches in all study years were similar at the three stations. Catches in 1980-1982 continued to show no pattern between the study areas (Fig. 17).

Alewives and rainbow smelt comprised, respectively, 90% and 7% by weight of all fish eaten by 15 rainbow trout. Invertebrates, especially terrestrial insects, constituted 67% of the food eaten by 75 rainbow trout <40 cm in length.

Slimy Sculpin

Just over 1,000 slimy sculpins were collected over the 10 yr. Annual catches varied almost 20 fold, from 272 fish in 1974 to 14 fish in 1978. The 199 fish caught in 1982 were the second-largest catch, while 1980 and 1981 catches were smaller than the 10-yr average of 105 fish per year. Eighty percent of the slimy sculpins were trawled, while 20% were seined.

Slimy sculpins prefer cold water, thus avoiding inshore waters during summer. The species moves shoreward in early spring to spawn, resulting in greatest inshore abundance in spring. A nocturnal shoreward movement also contributed to 85% of the total catch occurring at night. Slimy sculpins established a resident population on the plant's riprap, where spawning occurred (Dorr and Jude 1980).

Analysis of 1973-1979 trawl data showed that slimy sculpins are attracted to the plant's riprap (Tesar et al. 1985). However, annual abundance changes were similar in the two study areas. Consequently, plant operation, especially impingement mortality, does not appear to be decreasing slimy sculpin

abundance. Trawl data from 1980 to 1982 continued to show a greater abundance in the Cook area, presumably the result of the riprap attraction (Fig. 18). Statistical tests showed that the slimy sculpin catch at the Cook Plant in operational years was significantly larger than the Warren Dunes catch (Table 39). The catch at 6-m station C, which is the standard series station closest to the riprap, was also significantly greater than the catch at the Warren Dunes 6-m station.

Seine catches over the 10 yr showed no distinct trend among area catches (Fig. 18). However, catches were the smallest at Warren Dunes in 6 of the 10 study yr.

White Sucker

Almost 1,400 white suckers were collected over the 10 yr. Like longnose sucker catches, white sucker catches were relatively stable. Annual catches varied 2 fold, from 188 fish in 1979 to 89 fish in 1975 and 1976. Catches in 1980, 1981, and 1982 were near the 10-yr average of 137 fish per year. Seventy percent of all white suckers were gillnetted and 22% were seined.

White suckers were residents in the study areas and were captured year-round. This species moves shoreward at night, and 74% of the fish were caught at night.

Analysis of 1973 to 1979 gill net data revealed significantly larger catches at Warren Dunes during these study years (Tesar et al. 1985). Like longnose suckers, white suckers may avoid the Cook area because of plant construction and discharges. Catch data from 1980 to 1982 again showed larger catches at Warren Dunes (Fig. 18). Statistical tests of 1973-1982 data also showed significantly larger catches at Warren Dunes during all study years

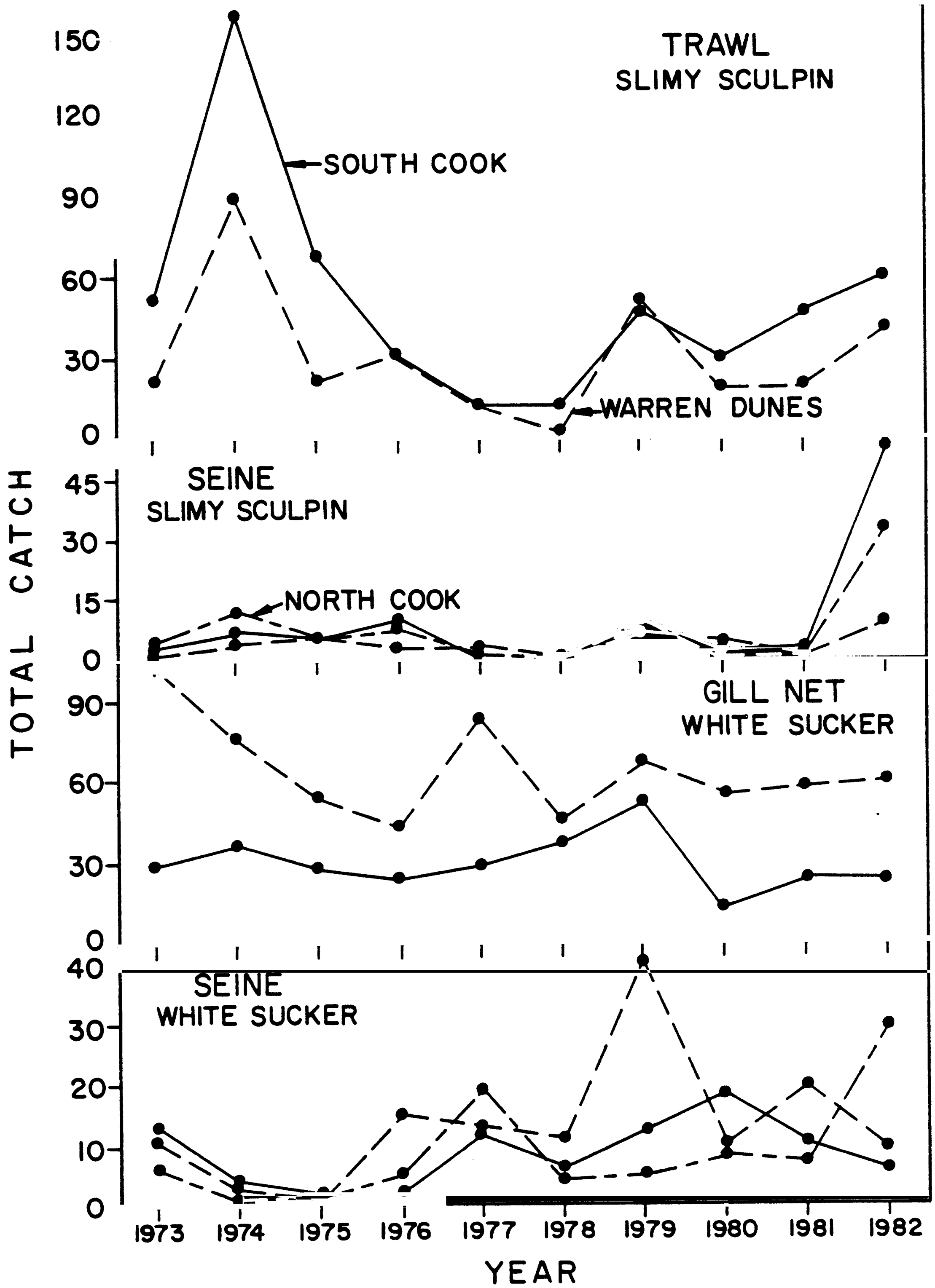


Fig. 18. Annual catches of slimy sculpins and white suckers in the study areas of southeastern Lake Michigan. The Cook Plant began operation in 1975.

Table 39. Results of the Kruskal-Wallis test applied to April, May, and June, 1973-1982 slimy sculpin night trawl catch data from Cook Plant study areas, southeastern Lake Michigan. Sta = stations(s), C = 6 m south Cook, D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes.

| Source of variation | H Statistic | Significance |
|---|---|---|
| Sta C (1973-74) vs. Sta G (1973-74) | 2.07690 | 0.1495 |
| Sta D (1973-74) vs. Sta H (1973-74) | 1.44230 | 0.2298 |
| Sta C,D (1973-74) vs. Sta G,H (1973-74) | 0.00333 | 0.9540 |
| Sta C (1973-74) vs. Sta C (1975-82) | 0.56519 | 0.4522 |
| Sta D (1973-74) vs. Sta D (1975-82) | 1.81720 | 0.1776 |
| Sta G (1973-74) vs. Sta G (1975-82) | 0.08132 | 0.7755 |
| Sta H (1973-74) vs. Sta H (1975-82) | 0.48992 | 0.4840 |
| Sta C,D (1973-74) vs. Sta C,D (1975-82) | 0.25828 | 0.6113 |
| Sta G,H (1973-74) vs. Sta G,H (1975-82) | 0.44262 | 0.5059 |
| Sta C (1975-82) vs. Sta G (1975-82) | 4.16710 | 0.0412* |
| Sta D (1975-82) vs. Sta H (1975-82) | 1.58210 | 0.2085 |
| Sta C,D (1975-82) vs. Sta G,H (1975-82) | 5.37870 | 0.0204* |

*Significant (P < 0.05).

(Table 40). Seine data demonstrated no consistent trends among station catches (Fig. 18).

RARE SPECIES

Forty-one species were categorized as rare in the study areas (Table 41). Rare species which were caught during a majority of the study years and which had a total catch greater than 50 fish were examined for catch differences between the two study areas. Bluegill, burbot, and ninespine stickleback catches were similar in the two study areas. Consequently, plant operation did not affect these species.

Total catches of channel catfish, emerald shiner, mottled sculpin, and northern pike were 2 times greater at Cook than at Warren Dunes. Larger catches at Cook also occurred in both preoperational and operational years. These findings suggest that these species are attracted to the plant's riprap and underwater structures. Presumably, this rocky substrate and broken topography are preferred over the sandy bottom elsewhere in the study areas.

Sixty-eight percent of the lake whitefish and 49% of the sand shiners were caught at Warren Dunes. Sand shiners were caught only by seining, and because there were two stations at Cook and only one at Warren Dunes, some preference by sand shiners for the reference station is indicated. These two species may be avoiding the Cook area because of the plant's discharges. Catches in preoperational years were too small to determine whether area abundances differed before the plant began discharging water.

Even though <50 fish of each were caught, golden redhorse, quillback, shorthead redhorse, and silver redhorse were caught in substantially greater numbers at Cook. Total catches at Cook were greater than 4 fold for each

Table 40. Results of the Kruskal-Wallis test applied to April through October, 1973-1982 white sucker gillnet catch data from Cook Plant study areas, southeastern Lake Michigan. Sta = stations(s), C = 6 m south Cook D = 9 m south Cook, G = 6 m Warren Dunes, H = 9 m Warren Dunes.

| Source of variation | H Statistic | Significance |
|---|---|---|
| Sta C (1973-74) vs. Sta G (1973-74) | 6.66120 | 0.0099* |
| Sta D (1973-74) vs. Sta H (1973-74) | 2.71220 | 0.0996 |
| Sta C,D (1973-74) vs. Sta G,H (1973-74) | 8.44890 | 0.0037* |
| Sta C (1973-74) vs. Sta C (1975-82) | 0.59847 | 0.4392 |
| Sta D (1973-74) vs. Sta D (1975-82) | 0.27411 | 0.6006 |
| Sta G (1973-74) vs. Sta G (1975-82) | 6.64960 | 0.0099* |
| Sta H (1973-74) vs. Sta H (1975-82) | 0.65200 | 0.4194 |
| Sta C,D (1973-74) vs. Sta C,D (1975-82) | 0.81073 | 0.3679 |
| Sta G,H (1973-74) vs. Sta G,H (1975-82) | 5.58650 | 0.0181* |
| Sta C (1975-82) vs. Sta G (1975-82) | 5.53520 | 0.0186* |
| Sta D (1975-82) vs. Sta H (1975-82) | 4.87230 | 0.0273* |
| Sta C,D (1975-82) vs. Sta G,H (1975-82) | 10.46300 | 0.0012* |

*Significant ($P < 0.05$).

Table 41. Total catch of rare species and number of years during 1973-1982 in which these species were collected at least once in Cook Plant study areas, southeastern Lake Michigan.

| Species | Total catch | Number of years | Species | Total catch | Number of years |
|---|---|---|---|---|---|
| Burbot | 76 | 10 | Lake herring | 3 | 3 |
| Ninespine stickleback | 113 | 10 | Rock bass | 4 | 3 |
| Channel catfish | 100 | 9 | Round whitefish | 8 | 3 |
| Lake whitefish | 53 | 9 | Central mudminnow | 3 | 2 |
| Sand shiner | 168 | 9 | Common shiner | 3 | 2 |
| Bluegill | 76 | 8 | Freshwater drum | 19 | 2 |
| Emerald shiner | 148 | 8 | Green sunfish | 7 | 2 |
| Silver redhorse | 25 | 8 | Smallmouth bass | 2 | 2 |
| Northern pike | 60 | 7 | Spotfin shiner | 5 | 2 |
| Golden shiner | 9 | 6 | White crappie | 6 | 2 |
| Largemouth bass | 8 | 6 | Banded killifish | 1 | 1 |
| Mottled sculpin | 57 | 6 | Blackchin shiner | 1 | 1 |
| Fathead minnow | 7 | 5 | Black crappie | 1 | 1 |
| Quillback | 14 | 5 | Blacknose dace | 1 | 1 |
| Shorthead redhorse | 18 | 5 | Blacknose shiner | 1 | 1 |
| Black bullhead | 8 | 4 | Creek chub | 1 | 1 |
| Bluntnose minnow | 4 | 4 | Grass pickerel | 1 | 1 |
| Lake sturgeon | 5 | 4 | Lake chub | 1 | 1 |
| Brook silverside | 3 | 3 | Logperch | 2 | 1 |
| Golden redhorse | 13 | 3 | Pumpkinseed | 1 | 1 |
| | | | Walleye | 1 | 1 |

species. Additionally, these species were not caught in preoperational years. These findings suggest that these catostomids are attracted to the plant's discharges, possibly as a source of food.

# SUMMARY

As part of environmental studies of the D. C. Cook Nuclear Power Plant, located on the shore of southeastern Lake Michigan 16 km south of St. Joseph, Michigan, fish were collected in the field during April-November from 1973 to 1982. Adult and juvenile fish >20 mm in length were gillnetted, seined, and trawled at the Cook Plant and at an undisturbed site, Warren Dunes State Park, 8 km south of the plant.

Just over 1,100,000 fish of 59 species were collected from these inshore, 0-9 m, study areas. Over the 10 yr, alewife, spottail shiner, yellow perch, rainbow smelt, and trout-perch were abundant in the study areas; bloater was also abundant from 1978 to 1982. However, alewife predominated, constituting 61% of all fish caught. Brown trout, chinook salmon, coho salmon, common carp, gizzard shad, johnny darter, lake trout, longnose dace, longnose sucker, rainbow trout, slimy sculpin, and white sucker were common (average catch >20 but <1,000 fish/yr) in the study areas.

Substantial differences in field catches between the two study areas were found for 12 of the 18 abundant and common species. In addition, 10 of 41 rare species also showed some catch differences between study areas. Of the 22 species showing catch differences, 16 species were caught in greater numbers at the Cook site while 6 species were more abundant at Warren Dunes.

The cause for these catch differences was assumed to be the power plant. Effects of the plant on fish were categorized as: (1) an attraction to the Cook area, (2) a repulsion from the area, and (3) an abundance decline possibly due to entrainment and impingement mortality. Attraction to the Cook area was further identified as resulting from: (1) the broken topography

created by riprap, underwater intake and discharge structures, and construction debris, (2) food organisms, such as crayfish, forage fish, snails, and other benthic invertebrates, living on the riprap, and (3) the warm-water discharge (including currents) and entrained food organisms.

Catches of brown trout, common carp, gizzard shad, golden redhorse, quillback, shorthead redhorse, silver redhorse, and adult yellow perch were consistently larger at Cook than at Warren Dunes in operational years. These species were apparently attracted to the discharges. Warm water and entrained food organisms were the primary attractants. Brown trout and adult yellow perch may also have been attracted to forage fish and crayfish inhabiting the riprap.

Catches of channel catfish, emerald shiner, johnny darter, longnose dace, lake trout, mottled sculpin, northern pike, and slimy sculpin were consistently larger at the Cook Plant during preoperational and operational years. These species were attracted to the broken topography at the plant site. The riprap served as residence habitat for johnny darter, slimy sculpin, and mottled sculpin. The riprap also served as spawning substrate for johnny darter, lake trout, slimy sculpin, spottail shiner, and yellow perch. Food organisms, such as crayfish and forage fish residing on the riprap, may have been an attraction for channel catfish and northern pike. The underwater structures and riprap may also have provided temporary shelter for channel catfish, emerald shiner, mottled sculpin, northern pike, and yellow perch.

A consequence of being attracted to the plant site is that species susceptible to entrapment will have a higher likelihood of being impinged. For example, slimy and mottled sculpins were impinged in greater numbers than field catches would have indicated.

During all 10 yr, catches of longnose sucker and whiter sucker were larger at Warren Dunes than at the Cook Plant. These sucker species avoid power plant sites apparently because of dredging during construction and discharges during operation. Lake whitefish and sand shiner catches were also larger at Warren Dunes, but only in operational years. These species also may be avoiding power plant discharges.

Spottail shiner and trout-perch trawl catches were significantly larger at Warren Dunes during operational years. Entrainment and impingement mortality may have decreased the abundance of these species. Although impingement mortality of other species is substantial, field catches during operational years demonstrated no abundance declines, with the exception of alewife, which declined lakewide.

The 10 yr of catch data revealed some major shifts in populations of three important Lake Michigan species. Alewives declined substantially after 1979, bloaters increased after 1977, and yellow perch increased after 1979. The sizeable bloater increase undoubtedly is a result of the closure of the commercial fishery in 1976. Decline of the alewife, a competing species, may have contributed to the bloater increase.

The primary cause for the alewife decline undoubtedly is salmonid predation. Mortality of alewives at water intakes has contributed to the decline. The substantial yellow perch increase would suggest that alewife depressed this species by preying on larvae. Emerald shiner larvae are also suspected of being preyed on by alewives. Thus, the emerald shiner population may increase; however, our data indicate that the current population is extremely small.

Consequences of the alewife decline in Lake Michigan are difficult to predict. Populations of other forage species, such as the deepwater coregonids, lake herring, rainbow smelt, spottail shiner, and trout-perch, as well as emerald shiner and yellow perch, should increase. However, if stocking rates of salmonids continue at current levels, these predators may switch to feeding on these other forage species. Whatever the changes, undoubtedly, major shifts in fish populations of Lake Michigan will occur in the 1980s.

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